

REPORT 37



**SWEED
SWEEP**

SOIL AND WATER
ENVIRONMENTAL
ENHANCEMENT PROGRAM



**PAMPA
PAMPA**

PROGRAMME D'AMELIORATION
DU MILIEU PEDOLOGIQUE
ET AQUATIQUE



SWEEP SWEEP

is a \$30 million federal-provincial agreement, announced May 8, 1986, designed to improve soil and water quality in southwestern Ontario over the next five years.

PURPOSES

There are two interrelated purposes to the program; first, to reduce phosphorus loadings in the Lake Erie basin from cropland run-off; and second, to improve the productivity of southwestern Ontario agriculture by reducing or arresting soil erosion that contributes to water pollution.

BACKGROUND

The Canada-U.S. Great Lakes Water Quality Agreement called for phosphorus reductions in the Lake Erie basin of 2000 tonnes per year. SWEEP is part of the Canadian agreement, calling for reductions of 300 tonnes per year — 200 from croplands and 100 from industrial and municipal sources.



PAMPA PAMPA

est une entente fédérale-provinciale de 30 millions de dollars, annoncée le 8 mai 1986, et destinée à améliorer la qualité du sol et de l'eau dans le Sud-ouest de l'Ontario.

SES BUTS

Les deux buts de PAMPA sont: en premier lieu de réduire de 200 tonnes par an d'ici 1990 le déversement dans le lac Erie de phosphore provenant des terres agricoles, et de maintenir ou d'accroître la productivité agricole du Sud-ouest de l'Ontario, en réduisant ou en empêchant l'érosion et la dégradation du sol.

SES GRANDES LIGNES

L'entente entre le Canada et les États-unis sur la qualité de l'eau des Grands Lacs prévoyait de réduire de 2 000 tonnes par an la pollution due au phosphore dans le bassin du lac Erie. PAMPA fait partie de cette entente qui réduira cette pollution de 300 tonnes par an — 200 tonnes provenant des terres agricoles et 100 tonnes provenant de sources industrielles et municipales.

TECHNOLOGY EVALUATION AND DEVELOPMENT SUB-PROGRAM

EFFECTS OF TILLAGE ON THE QUALITY AND
QUANTITY OF SURFACE AND SUBSURFACE
DRAINAGE WATER: UPLANDS

FINAL REPORT

January, 1992

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**EFFECTS OF TILLAGE ON THE QUALITY AND QUANTITY OF
SURFACE AND SUBSURFACE DRAINAGE WATER**

**Soil Water Environmental Enhancement Program
Technology Evaluation and Development Subprogram Project#**

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reflect the views of the Government of Canada or
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EXECUTIVE SUMMARY

A study was undertaken to determine the effects of tillage system on the quantity and quality of surface runoff and tile drainage water. Previous studies have suggested that the increased infiltration and occurrence of macropores in no-till systems may increase the risk of movement of chemicals to the groundwater. Thus, no-till systems may solve one problem (surface water quality), but create another problem (groundwater quality).

The study was carried out on the long term no-till - moldboard plough comparison established by Don Lobb, a conservation farmer near Clinton, Ontario. The soil at the site is a sandy loam. Three tile lines in each of the two tillage systems were instrumented for monitoring tile flow quantity and the concentrations of nitrate nitrogen and phosphorus.

Multi-level groundwater samplers were also installed in each treatment, and soil coring and the application of tracers (chloride) was used to track the movement of soluble chemicals. Detailed solute transport experiments under controlled application of water were also carried out to characterize the soil transport properties. The installation of equipment was started in the fall of 1988 and finished in spring of 1989. The site was planted with corn in 1989 and soybeans in 1990.

Surface runoff was monitored by installing runoff collection flumes on selected soil landscape positions within the study field. Rainfall simulation studies and characterizations of the hydraulic soil properties controlling surface runoff were also carried out in cooperation with other studies.

No significant tile flow was recorded until late fall 1989. From Oct. 1, 1989 to Oct. 1, 1990 a total of 121 cm of precipitation was recorded. Total tile flow amounted to approximately 19.0 cm with no significant differences between tillage systems. Movement of water below the tile line was significant and estimated at 49 cm of water.

No-till had significantly higher average concentration and water flux averaged concentration of $\text{NO}_3\text{-N}$ in the early spring and fall periods compared to moldboard, but the reverse was true in the late fall. The average concentrations in both systems exceeded the drinking water quality limit of 10 mg $\text{NO}_3\text{-N/l}$. The average concentration was 10.7 mg $\text{NO}_3\text{-N/l}$ in both systems.

Total nitrogen leaching from the 1989 corn crop was estimated at 80 kg N/ha and 50 kg N/ha in the no-till and conventional till systems respectively. The increased N leaching in the no-till was attributed to a higher N soil test in the no-till system and a requirement for less N fertilizer than the moldboard systems. Both systems had the same

fertilizer applied (160 kg N/ha). The amount of N lost by leaching in each replicated plot was significantly correlated to the difference between the fertilizer N applied and the fertilizer amount required according to the N soil test.

Detailed transport studies indicated more macropore transport in the moldboard plough system than the no-till system. However, the average solute transport velocity was faster in the no-till, which was attributed to increased occurrence of blocked pore domains.

The no-till system should not result in an increased risk of chemical contamination of our groundwater resource. If the nitrogen soil test is used to determine fertilizer requirements then the occurrence of over-application of N fertilizer should be significantly reduced in all tillage systems.

Surface water runoff from both the no-till and moldboard treatments was negligible at this site. This was attributed to the very high infiltration rates of the sand-loam soil. Runoff simulation indicated that increase water runoff would be expected in the no-till treatment for very large rainfall events. However, total phosphorus loss would be 2 to 4 times lower than the moldboard treatment.

Dissolved ortho-phosphorus and nitrate N in runoff water was also very low in the sandy-loam textured soil. However, runoff simulation on a clay-loam textured part of the field indicated that ortho-phosphorus in the runoff was significantly higher in the no-till compared to moldboard treatment. This, combined with an increased runoff volume from the no-till may be a problem in heavier textured soils.

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1. INTRODUCTION

Conservation tillage has been suggested as a method of reducing the movement of sediment and chemicals in surface runoff from agriculture fields. A number of studies have measured increased infiltration, decreased surface runoff and decreased erosion in conservation tillage compared to conventional tillage systems. The increased infiltration has been attributed to an increase in stable continuous macropores under conservation systems, especially no-tillage systems. A review of the impacts of conservation tillage on water quality has been given by Baker and Lafren (1983).

Other studies have shown the opposite results with conventional till having higher infiltration rates and saturated hydraulic conductivity values, and lower runoff than minimum or zero-till (Lindstrom et al. 1981; Lindstrom and Onstad, 1984). Recent SWEEP studies also indicated that no-till resulted in decreased porosity, decreased saturated hydraulic conductivity and increased runoff (Kachanoski et al. 1989, O'Neill et al. 1990).

1.1 Study Justification

The possibility of increased water infiltration and occurrence of macropores in no-till systems compared to conventional tillage systems raises the concern that increased movement of chemicals to the groundwater may occur in the no-till system. Thus, a possible solution for surface water quality (no-till) may be creating a problem with sub-surface water quality.

2.0 OBJECTIVES

The objectives of this study were:

1. Examine the quantity and quality of surface water and water moving to the tile drains under no-till and fall moldboard plough tillage systems;
2. Determine the mechanisms responsible for changes in water loss (quantity and quality)
3. Identify potentially negative water quality impact of conservation tillage and possible preventional remedial measures and,
4. Identify areas of future research.

The effects of the tillage treatment on surface runoff quantity and quality were also examined at the same site by the following cooperative research projects;

1. Event based soil and phosphorus loss Min. of Env. Project 913. (J. Eddy, Scientific Liaison).
2. SWEEP-TED: Effect of management on surface hydraulic properties: method development (Dr. W. Findlay, Scientific Authority).

3. SWEEP-TED: Management of farm field variability (Dr. W. Findlay, Scientific Authority). This site is one of many being monitored.

The Partners In Nitrogen Project a cooperative project with the Ont. Ministry of Agriculture and Food, and the Fertilizer Institute of Ontario helped to cover the extra costs of installing the groundwater multi-level samplers and subsequent analysis of the water samples.

3.0 METHODOLOGY

3.1 Site Description

The study site selected was the Tillage-2000 site at Don Lobb's Farm, location on concession road 15-16, Goderich Township, just north of Clinton, Ontario (Figure 3.1). The soil on the drainage plots is sandy loam in texture. The site has one of the longest running field scale tillage comparisons in Ontario. At the start of the study October, 1988) a no-tillage and fall mouldboard plough comparison had already been in place for 8 years. Yield data, residue levels, and management have been documented for the treatments. The site had also been intensively sampled for Cesium-137 for monitoring annual soil loss rates, as part of the SWEEP-TED Management of Farm Field Variability Project.

A schematic field plot map is shown in Figure 3.2. There are three replications of each tillage treatment (moldboard, no-till), with replications paired by slope position and distance to the municipal drain. Each treatment replication is separated hydrologically from the adjacent plot by a tile line which runs exactly on the border of the plots. This provided good drainage separation between treatments and replications. The average distance between tile drains is approximately 13 m and the plot lengths are 70 m. The average depth to the tile lines is approximately 0.75m. Additional header tiles were installed for this project (locations A and B, Figure 3.2) to isolate the replications and accomplish the field design. This was carried out by a sub-contract (Bayline Drainage, Ltd.) in October, 1988. Additional header tiles were also installed to transport the drainage water to the municipal drain and eliminate any back pressure in the tile lines. A summary of plot dimensions of each replication is given in Table 3.1.

A topographic contour map of the study site is given in Figure 3.3. The topographic data were collected using a laser theodolite with point observations on a 10 m x 10 m (approximate) grid. The surface slope is towards the corner of the field and plot #1, and towards the existing municipal drain.

3.2 Tile Monitoring Stations

Six tile drainage monitoring stations were installed in the fall of 1988, on the tile line in the centre of each tillage replication (Figure 3.2).

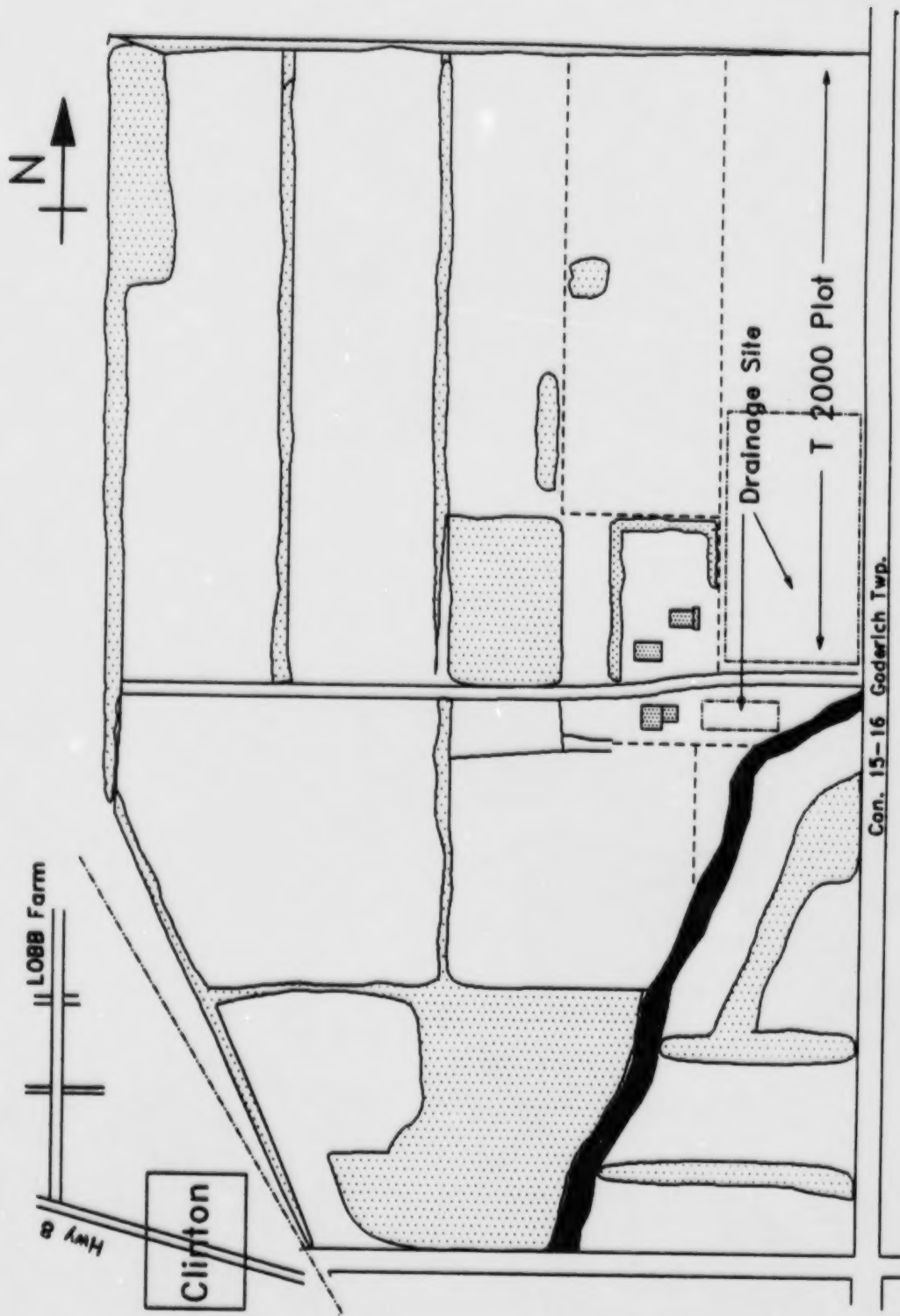


Figure 3.1. Location of study site at D. Lobb Farm.

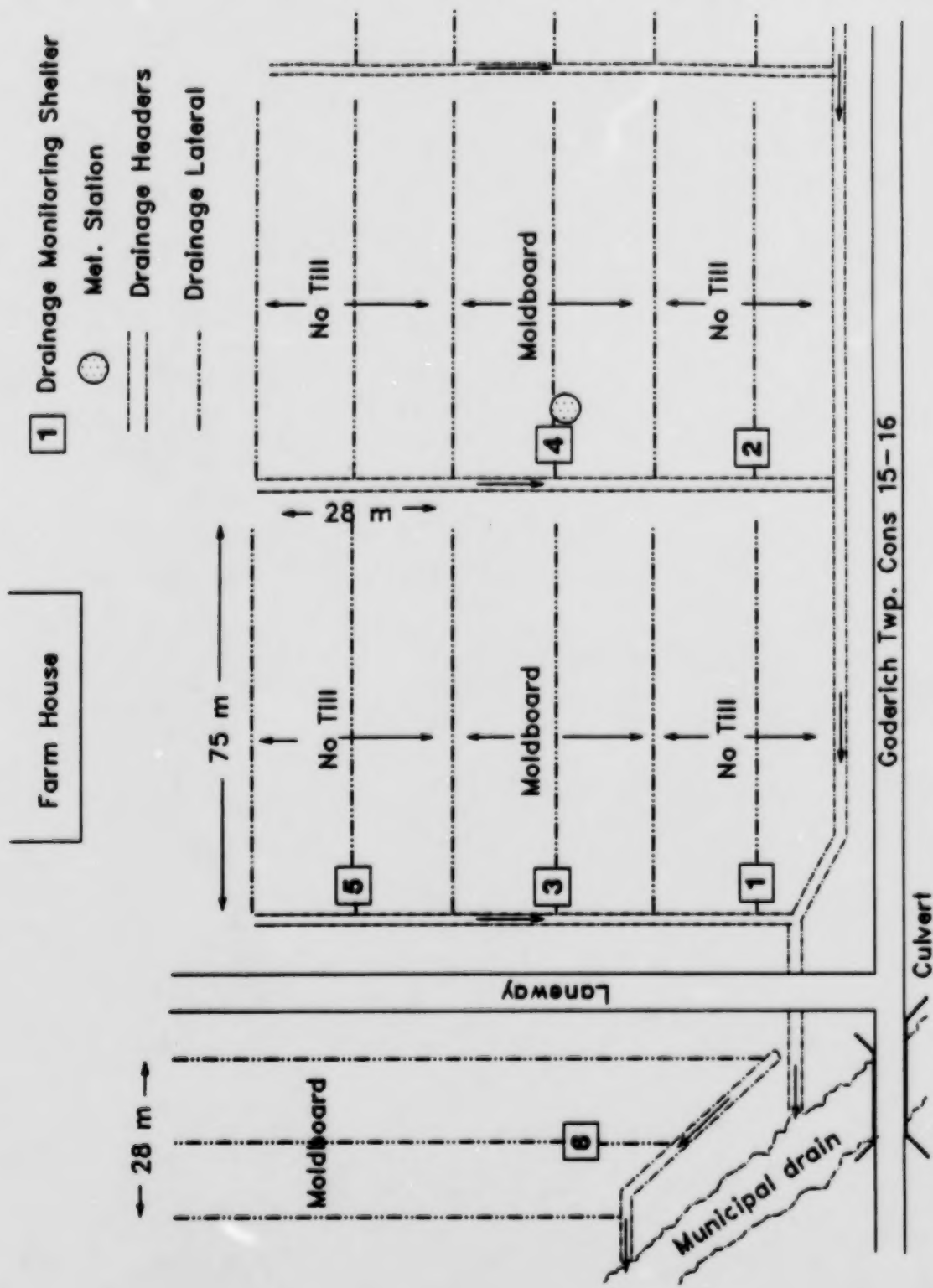


Figure 3.2 (a): Research Plot Design

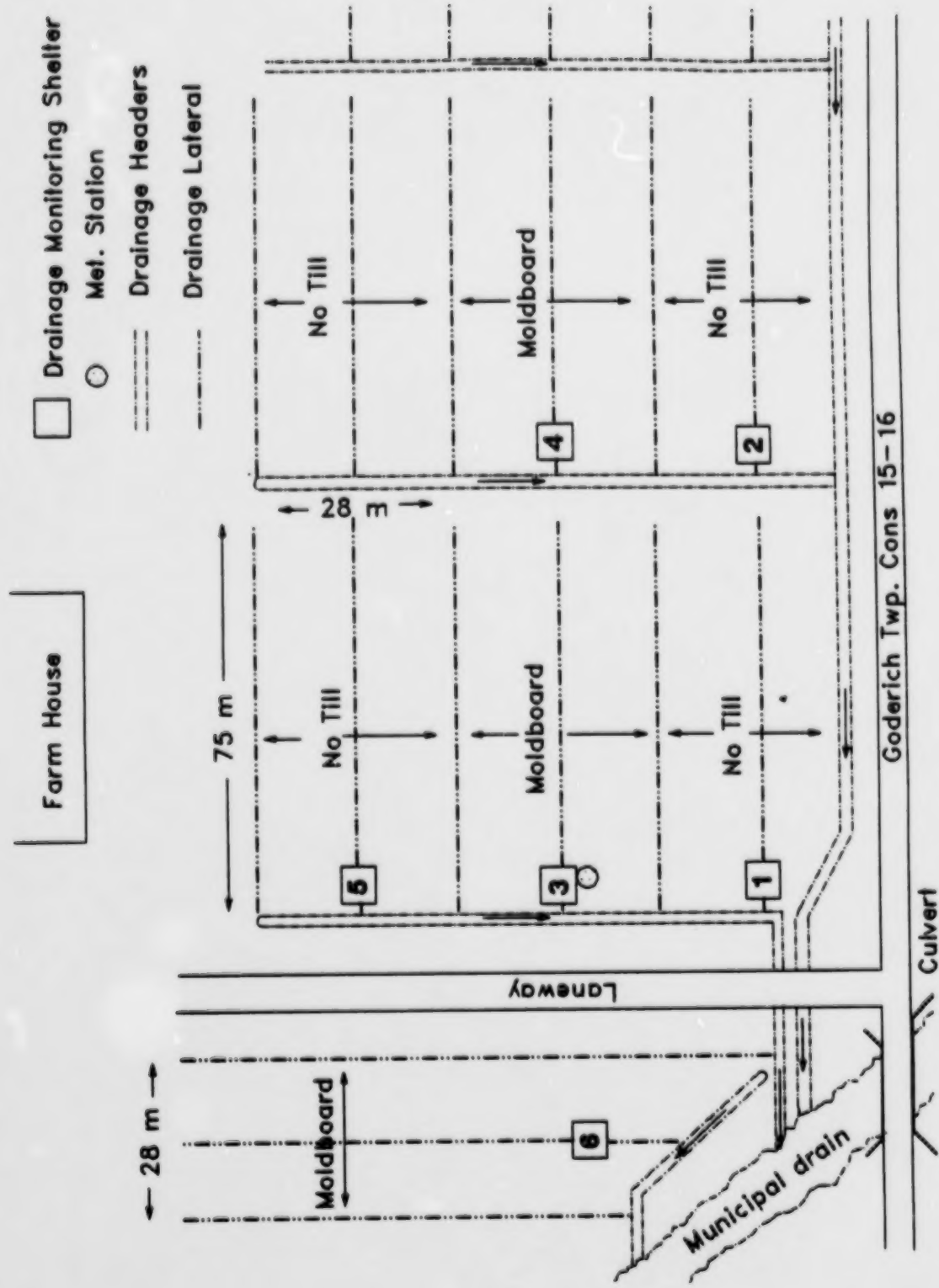


Figure 3.2 (b): Research Plot Design after spring 1990.

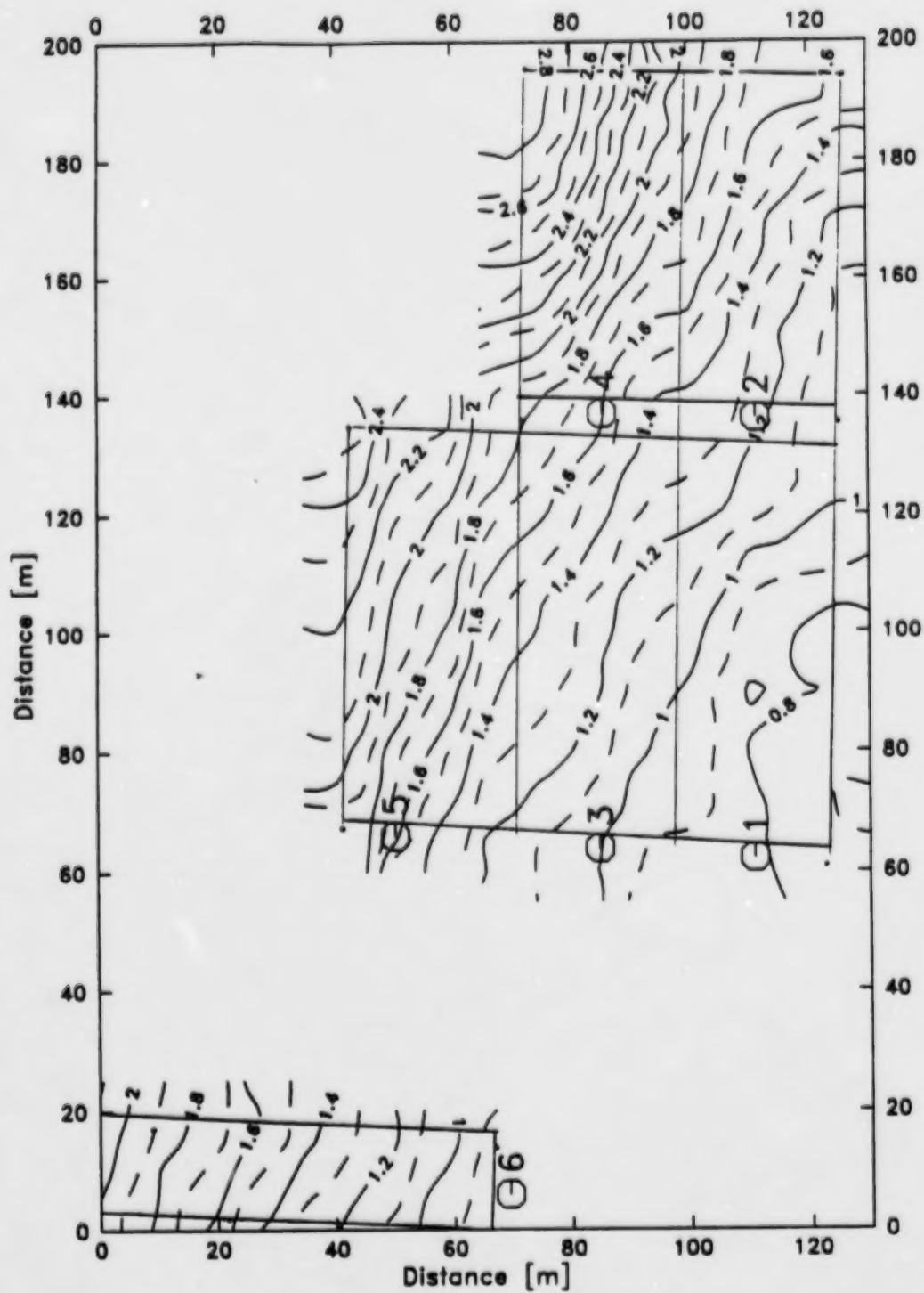


Figure 3.3: Topographic contour map of Drainage Site

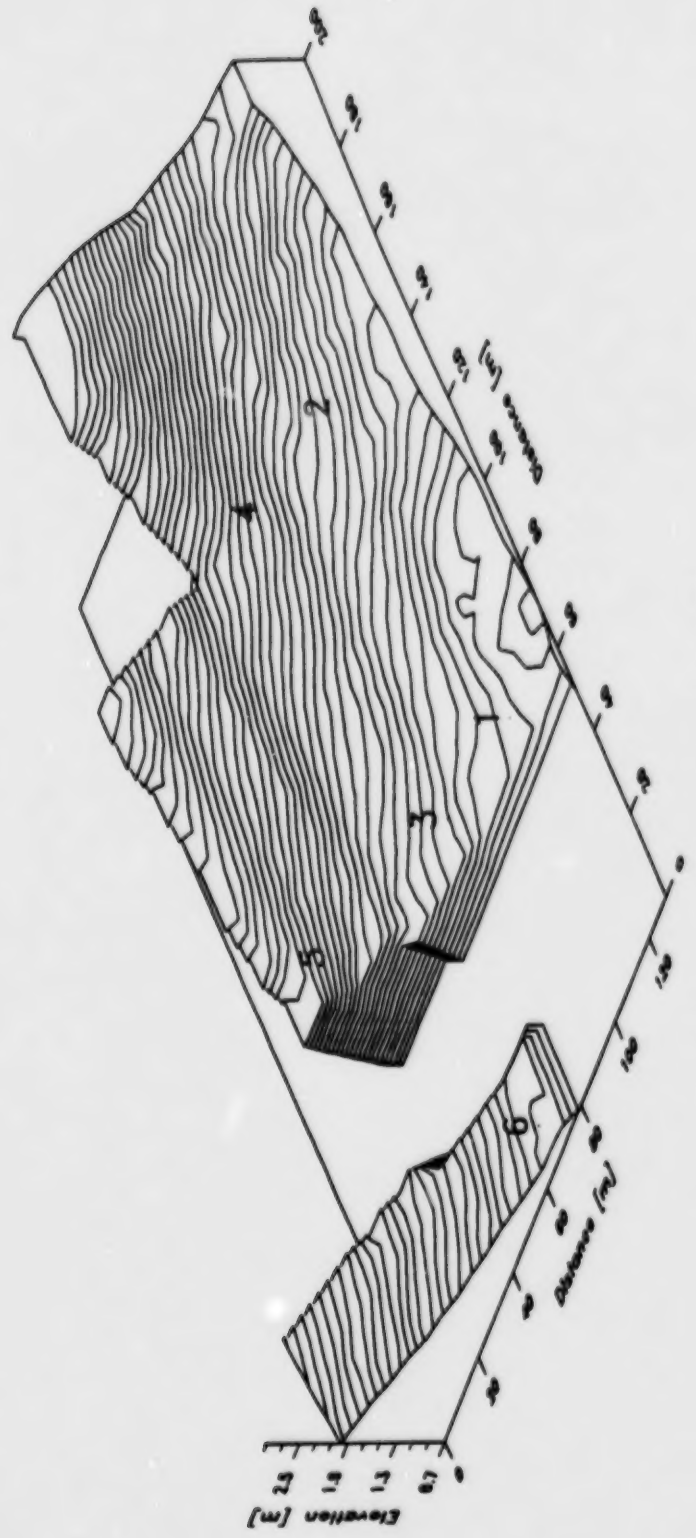


Figure 3.3 (a): Relief map of Drainage Site

Drainage access housing

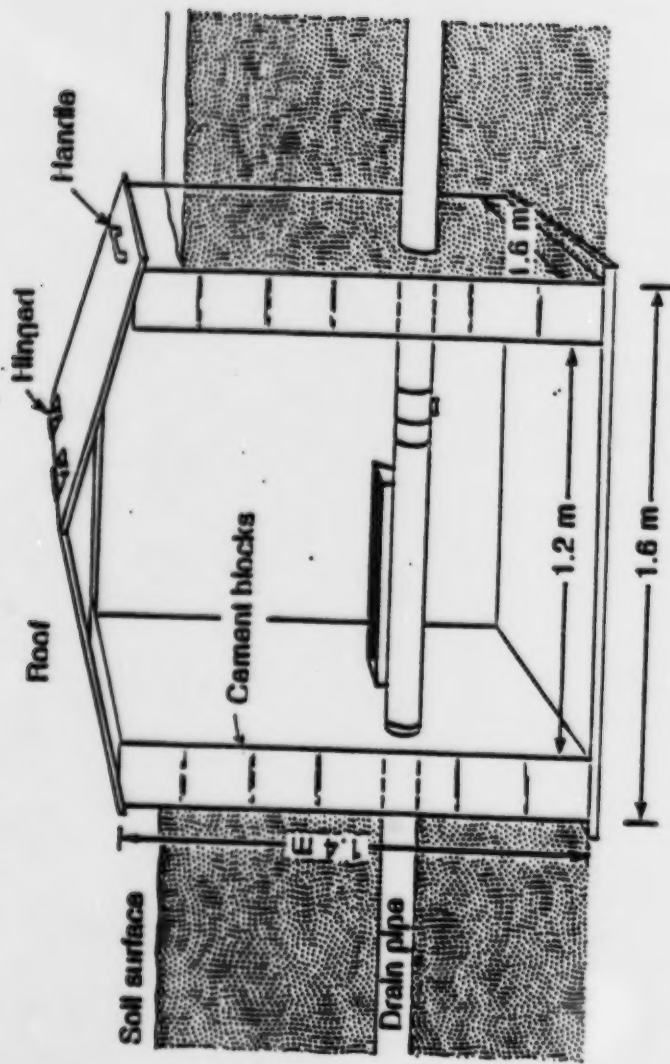


Figure 3.4: Drainage monitoring station.

A diagram of the tile drainage monitoring stations (six installed) is shown in Figure 3.4. A hole was excavated around and below (30 cm) the tile line to be monitoring using a back-hoe (sub-contract Bayline Drainage Ltd., Clinton). The perforated tile line intercepted by the excavation was replaced by a solid section of PVC pipe of the same diameter (4 inch). The bottom of each excavation was levelled while continually pumping out seepage water. (Construction was late fall and water table was above the laterals. After the bottom of the hole was levelled a based layer (15 cm thick) of coarse pea-gravel was laid down. A square wooden form 1.6 x 1.6 m (0.15 m high) was placed on top of the gravel base and heavy water proof concrete was poured into the frame to create the base floor of the structure.

After the concrete base had hardened, a concrete block structure (8" blocks) was constructed around each of the monitoring laterals. After the block housings were constructed, water proofing cement parging was applied to the outside of the walls, then a plastic liner, and then the hole was back filled around the structure.

At the top of the structure, bolts were cemented in, and a hinged roof (clear polymer plastic) was bolted to the structure.

3.3 Instrumentation

Each of the solid monitoring pipes have a downspout valve inserted into them, which will cause all of the tile flow to be intercepted and temporarily shunted into the drainage housing. This allowed a direct measurement of tile flow, which was then calibrated against water height in the tile line.

Water height in the tile lines was recorded continuously by installing very sensitive water pressure transducers which gave a 0-5.0 volt full scale output for 0-25 cm of water height. The transducer was connected and controlled by a Cambell CR-21x data logger, which recorded the analog signal. A summary of the controlling CR21x program for the transducer is given in Appendix I, along with a laboratory calibration of the pressure transducer at 5°C and 24°C. As indicated, the calibration line at the two temperatures is exactly the same and no temperature correction was necessary in the field.

The pressure transducers, though very accurate were extremely sensitive to freezing events, with the pressure diaphragm in the sensor cracking if any ice was formed. To assure continuous data collection, a stilling well and automatic recording float gauge as also installed on all tile lines. In addition, electrical power lines were run to each housing and heating cable was wrapped around the instrumentation. The temperature in the housings were also kept above freezing by insulating the inside of the housings and installing a 200 watt light bulb to generate heat.

In summary, flow was monitored on all six plots using a combination

Table 3.1 Field plot characteristics.

Plot Characteristic	Site Number					
	1	2	3	4	5	6
Tillage	NT ^a	NT	MB ^a	MB	NT	MB
Length (m)	70	70	70	70	70	66
Width (m)	10	10	13	13	19.5	10
Area (m ²)	700	700	910	910	1365	660

NT = no-till, MB = moldboard

Table 3.2 Cropping history for Lobb site

1988

Soybean

1989

May 1 Herbicide Roundup, 1.7 L/ha

May 4 Corn; Pioneer 3790, 66700 pl/ha
Fertilized with 10-26-23 @ 280 kg/ha

Sidedress, 28% N (375 L/ha) = 134 kg N/ha

May 6 Dual, 2.5 L/ha; Atrazine, 2 kg/ha

1990

May 20 Blazer (Low dose)

May 21 Herbicide; Dual 1.2 kg/ha, Linuron 0.9 kg/ha

May 22 Planted soybean, 90 kg/ha Pioneer 0877
Fertilized 13.5 kg/ha P, 3.4 kg/ha K, 3.4 kg/ha N

June 20 Basagran 0.8 kg/ha

1991

May 9 Corn; Pioneer 3751, 66700 pl/ha
Fertilized with 15-30-10, 196 kg/ha

May 24 Sidedress 28% N, (375 L/ha), 134 kg N/ha

of the pressure transducers, float gauges and manual measurements. A field technician (local) visited the site almost daily and recorded manual measurement of the height of water in the flowing tile lines.

Flow was calculated from the height of water in the tile line and the slope of the tile line (measured) using a modified Manning equation calibrated for the tile lines. (Flow $Q(\text{cm}^3/\text{min})$ was calculated from

$$Q = K_c \frac{A^{5/3}}{P^{2/3}}$$

where, $p = 2r\theta$

$$A = r^2\theta - \frac{r^3}{2}\sin 2\theta$$

$$\theta = \cos^{-1}\left(1 - \frac{h}{r}\right)$$

$$K_c = s^{0.5}/n$$

and r = radius of tile line, h = height of water in the tile line, s = slope of tile line and n = roughness coefficient. The roughness coefficient n is the only unknown quantity (all else are measured). The roughness coefficient can be measured for the tile line by measuring Q insitu along with h .

Each of the six monitoring stations had an ISCO automatic water sampler which took a water sample every 6 hours during the fall-spring period. The sampler was set to take samples every 12 hours in the summer regardless of the occurrence of flow. Water samples were collected daily by an on-site technician and frozen immediately in a freezer at the site. The samples were then periodically shipped back to the University of Guelph and analysed for $\text{NO}_3\text{-N}$, and chloride. Total P and ortho-phosphorus were also analysed but not as frequently.

A meteorological station was set up to record rainfall, temperature, windspeed, humidity, and total solar radiation. A total rain gauge was also installed at the site.

3.4 Soil and Groundwater Sampling

In addition to monitoring tile flow, soil cores were taken (1.0 m

depth) approximately every month from each of the replicated plots. The cores were sectioned into 5-15 cm intervals and analysed for $\text{NO}_3\text{-N}$.

In the fall of 1990, 12 multilevel groundwater samplers were installed to monitor water quality from near the top of the water table (0.95 m) to a depth of approximately 5.0 m in 0.30 m increments. Two multilevel samplers were installed per treatment replication (total = 12), one directly under the monitored tile line, and the other "at one-half of the tile line separation distance. The multilevels were sampled periodically to determine the location and movement of a field scale chloride pulse applied on Nov. 1, 1989.

3.5 Field Scale Chloride Tracer Test

A field-scale tracer test was started on Nov. 1, 1989. A field scale spreader applied $1000 \text{ kg Cl ha}^{-1}$ as KCl over the entire research site. The drainage water was subsequently analysed for Cl^- . Soil cores were also taken to determine the movement of the Cl^- through the unsaturated zone. The multilevel samplers were subsequently used to determine the rate of vertical movement once the tracer reached the groundwater. The drainage water was also analysed for chloride.

3.6 Tillage Effects On Solute Transport Velocities (part of the M.Sc. work by E. Pringle)

In the summer of 1990, an experiment was initiated to examine solute transport properties such as velocity and dispersivity in the unsaturated zone of the study area in both the no-till and moldboard plow systems. The specific objective of this research was to determine if water which may contain dissolved pesticides or fertilizer would reach the groundwater sooner in one management system than the other. Essentially, the experiment involved the application of a non-reactive tracer whose movement was tracked through the soil.

3.6.1 Development of a Rapid Method of Estimating Solute Transport Parameters

This part of the study was carried out in conjunction with funds from the Natural Sciences and Engineering Research Council (NSERC). A limiting step in our understanding of solute transport through unsaturated field soils is the lack of experimental data. Field solute transport characteristics such as the travel time density functions $f_L(t)$ for different soil depths are often very difficult and time consuming to measure. The objective of this work was to develop a method to measure $f_L(t)$ for a conserving tracer added as a pulse under conditions of constant rate of applied water and steady-state water content.

A detailed summary of the theory, equations and analysis of data collected using this method is given in Appendix II. The method has also been published in a scientific journal (Kachanoski, et al. 1991). In

short, the method involves measuring the voltage attenuation of a reflected electromagnetic signal Time Domain Reflectometry (TDR) which permits the estimation of bulk electrical conductivity. The electromagnetic wave is generated by a Tektronix 1502 cable tester and travels along a wave guide. The wave guide consists of two parallel stainless steel rods (probes) which are inserted into the soil to the desired depth. The cable tester has an oscilloscope screen which is used to measure the change in the attenuation of the signal over time.

At constant soil water content (θ), this TDR estimate of bulk electrical conductivity (EC_A) is related to the average pore water concentration of an added solute tracer, which in turn, is related to the total specific mass ($g\ m^{-1}$) of the tracer existing within the zone measured by the TDR probes. The application of this method to obtain solute transport parameters by fitting models to the data is given in Appendix III. This work has also been submitted for publication in a scientific journal (Elrick et al. 1991).

3.6.2 Clinton Small Scale Tracer Experiment

Four replicate plots measuring 2 m x 2 m each were established on each tillage system. All vegetation (soybean) was removed from the plots by cutting plant stems at the soil surface. This was necessary to ensure that all water movement was downward into the soil and not taken up by the plants. TDR probes of different lengths were installed vertically in a grid pattern within the inner square metre of each plot. The soil depths of most interest were 20 and 40 cm as they represented the A and B horizons. Thus, a total of 10 pairs measuring 20 cm and 10 pairs of 40 cm length were inserted into the soil in each plot. Two pairs 10 cm in length and 2 pairs measuring 70 cm were installed at the plot corners to provide information at shallow and deep depths respectively. These probes were then connected by wire leads to central access boxes where they could be monitored without disturbance to the site.

Once the plots were established, a slow rate of water application over the entire 4 m² was initiated on July 21 to bring the soil to steady-state water content. The water application rate was 1 cm per day. Previous attempts had been made to wet the soils in nearby sections of these fields with higher application rates but the soil's infiltration rate was so low and the groundwater table was so shallow that ponding occurred within a few hours. Water was applied to the soil surface once each day by hand using a submersible pump with a hose and nozzle. Care was taken to apply the water as evenly as possible. Water content was measured and recorded twice daily (every 12 hours) using TDR. All plots were covered with black plastic to limit evaporation and ensure no additional water was supplied by natural rainfall.

On July 30, when the water content no longer increased, the tracer experiment began. This involved mixing Potassium Chloride (KCl) to one day's water supply and applied in the same manner as the water. KCl concentrations were such that a total of 100 gm³ was applied to each plot. Salt-free water application continued daily but now ohms readings (resistance) were taken directly from the TDR screen and recorded every 12 hours. Water contents were still taken periodically to ensure that steady-state water content was being maintained. The salt content of the soil increased as a result of the tracer application. This, in turn, causes the resistance (ohms) reading measured by the probes to decrease drastically. As the salt exited the area measured by the TDR probes, the resistance increased again.

The water application and ohms recording continued on all plots until August 24. At this time most of the ohms readings had returned to the value recorded prior to salt application for the 10, 20 and most of the 40 cm probes. This meant that all of the salt had travelled past these probes. Monitoring continued on half of the plots (2 replicates for each system) until September 1. Although not all ohms readings had returned to their initial value, the experiment was terminated because the ohms readings had levelled off and did not appear to be increasing.

All ohms readings from all 8 plots were transformed to mhos (electrical conductivity) and each curve was normalized to account for any variation in salt application and water content among plots. Solute mass breakthrough curves were calculated according to the theory and methods outlined in appendix II. Breakthrough curves from each system were then averaged to obtain a "field-scale average breakthrough curve" for the no-till and conventional management system.

The analysis of these data allow for the determination of solute breakthrough curves for each depth measured. Two methods of breakthrough curve analysis were used to obtain quantifiable characteristics for each curve that would lend themselves to comparison between systems. Both methods involved fitting the curves to models. All calculations were performed using the Mathcad program. A detailed summary of these procedures and the Mathcad spreadsheet program are given in Appendix III.

In brief, the first model was the Convective Dispersion Equation (CDE) which is a deterministic model that accounts for solute movement resulting from convection and dispersion. The equation to model the solute's exit from the region of measurement is (Appendix III):

$$N(ct, D, V) = 0.5 \cdot (1 + \operatorname{erf} \frac{(L - Vct)}{2\sqrt{Dct}}) - 0.5 \cdot \exp \left(\frac{VL}{D} \right) \cdot (1 - \operatorname{erf} \frac{(L + Vct)}{2\sqrt{Dct}})$$

where: erf = error function
 t_e = time (hr)
 L = length of TDR probes (cm)
 V = mean pore water velocity (cm hr⁻¹)
 D = dispersion coefficient (cm²hr⁻¹)

A dispersion coefficient (D) and mean pore water velocity (V) were obtained for each curve using this technique. Mean solute travel time (t_L) was also calculated using the following relationship:

$$t_L = \frac{L}{V}$$

The other method of analysis involved fitting the observed curve to a Convective Lognormal Transfer function (CLT) which is a probability distribution function that represents the distribution of velocities at which solute particles travelled. This function is represented by:

$$N(t_e, \sigma, \mu) = 0.5 \cdot (1 - \text{erf}(\frac{\ln(t_e) - \mu}{\sqrt{2} \cdot \sigma}))$$

Where: μ = the mean of the distribution (hr)
 σ = the variance of the distribution (hr²)

Population means (μ , expressed in hr) and population variance (σ^2 , expressed in hr²) which permit comparisons with the CDE results, were calculated using the following equations also presented in the appendix.

$$\mu_p = \exp(\mu + \frac{\sigma^2}{2})$$

$$\sigma_p^2 = \mu_p^2 \cdot (\exp(\sigma^2) - 1)$$

This model is completely stochastic and assumes direct correlation between the speed at which a solute particle travelled at one point of measurement. It does not consider random movement by the solute particles.

Moment analysis was also attempted to determine the average travel time and the variance of solute travel time of the breakthrough curve without forcing a model to the data. This was attempted by fitting a spline function to the TDR data and taking the first derivative of this curve. This differentiated curve is equivalent to the probability density

function (pdf). However, slight fluctuations in water content between the morning and evening TDR readings coupled with the effect of temperature on the soil's electrical conductivity, the breakthrough curve did not always form a smooth line. Hence, the pdf did not exhibit a discernible peak and therefore, moment analysis was deemed inappropriate for this particular data set.

In addition to the curve fitting techniques, the time for 5, 50, 90 and 95 percent of all solute to travel 20 and 40 cm was determined by reading the times directly from the model-fitted data. Percent solute recovery was also calculated by using the following equation.

$$S = \frac{(R_f - R_i)}{R_i} \cdot 100$$

Where: S = % solute recovery

R_f = final TDR reading (ohms)

R_i = initial TDR reading (ohms)

This was done of reach probe pair and averaged for each management system at the two depths. T-tests were performed at $\alpha=0.05$ using STRATGRAPHICS (STSC Inc. 1989) to determine if any significant differences existed.

3.7 Surface Runoff and Hydraulic Properties

Measurements of surface water runoff and quality were carried out in cooperation with a project funded by the Ontario Ministry of Environment.

3.7.1 Runoff Site Locations

The tile drainage plots are situated at one end of the front field of D. Lobb as indicated in Figure 3.1 and Figure 3.2. A three dimensional relief map of the site is given in Figure 3.5 showing the reasonably level front part of the field where the drainage experiment occurred and the presence of hills and ridges in the back part of the field. As indicated, the overall field slopes up from front to back, but with an overall slope of only 1% (5.5 m in 570 m). Surface runoff for the front of the field starts at a ridge running across the field at a distance of approximately 280 m. This ridge is shown more clearly in the contour intervals given in Figure 3.6. The soil from the front of the field to the ridge (0-280 m) is a mixture of loamy-sand and loam material. The soil on the other side of the ridge is a silty-loam, and the back part of the field is a clay-loam texture.

The tillage-2000 plots at this site ran the length of the field, parallel to the long axis (570 m) in Figure 3.5. Thus, the ridge at 280 m and the sloping clay loam soil at the back were split into two managements, no-till and conventional moldboard MB, similar to the drainage experiment. Surface runoff monitoring occurred within the two

Tillage-2000 treatments and was carried out mostly on the front and back slopes of the first ridge at 280 m. The soil on this ridge is very similar to the drainage experiment. Runoff collectors for natural events were also installed at the back end of the site on the clay-loam soil. The goal for this part of the study was to use rainfall simulation to assess the quality of the runoff water from both treatments and also to collect runoff water and sediment from natural events using runoff collection systems.

3.7.2 Natural Runoff

A total of 12 runoff plots (6 per tillage treatment), each 10 m long x 1.6 m wide were installed in the summer of 1988 as part of the MOE project. The large plot width allowed the monitoring of two complete corn rows (@ 0.8 m planter spacing). The plots were located on the upper and lower slope positions of both sides of the ridge at 280 m, on both tillage treatments (total = 8 runoff plots). The remaining 4 plots were as paired plots (tillage treatments) on two mid-slope positions in the clay-loam soil at the back of the field.

The overall slope of the first ridge is approximately 5% with 2-5 m sections having local slopes of up to 7%. The average slope on the runoff plots in the first ridge was approximately 6% which is typical of upland areas. The slopes of the heavier textured sites averaged 3-4%.

The runoff installations at each of the 12 plots for monitoring natural rainfall events are shown diagrammatically in Figure 3.7 and in more detail in Figure 3.8. The runoff troughs (Figure 3.8b) were custom made from galvanized metal. At the edge of the trough where it joins the plot area a small downward facing lip has been inserted into the soil to make a good seal. Two square galvanized metal pipes carry the sediment and water to a square collection tank made of 16 gauge galvanized metal. The tank was 1.2 m x 0.5 m x 1.15 m (Figure 3.8) for a total volume capacity of 0.69 m³. The collectors hold a total of at least 4 cm of runoff water from the runoff plots, which should have had the capacity for most, if not all, precipitation events. The collection tanks were to be emptied after each major rainfall event and the runoff water and sediment then analysed.

In addition to measuring the total amount of runoff and sediment, the installations were also instrumented to measure runoff hydrographs for the natural-events. This was done by continuously measuring the volume of runoff water in the collection tanks using custom constructed float gauges (Figure 3.9) which were attached to a continuously recording data logger. The float gauges were designed by the researchers as a cost effective method of measuring water level. The gauges were constructed for approximately \$300.00. It sends a 0-5 volt full scale signal for a change in water level of 0-90 cm. The range of water height measured for full

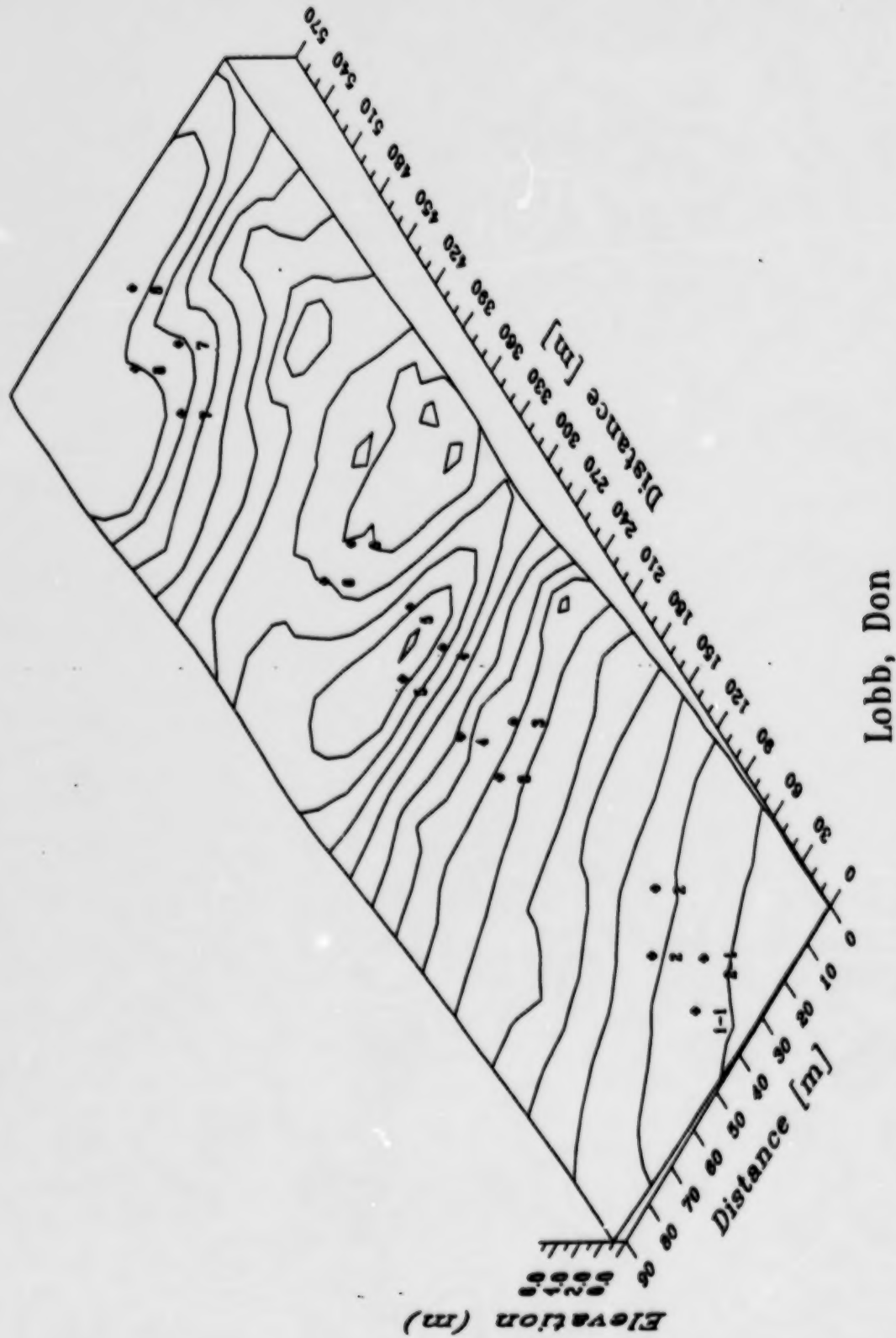


Figure 3.5: A relief map of the Lobb T2000 site.

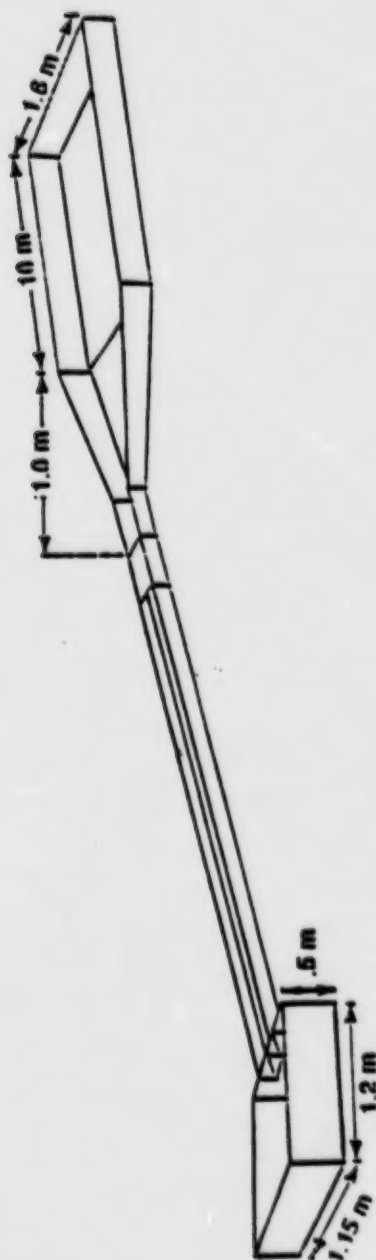


Figure 3.7: Diagram of permanent runoff installations.

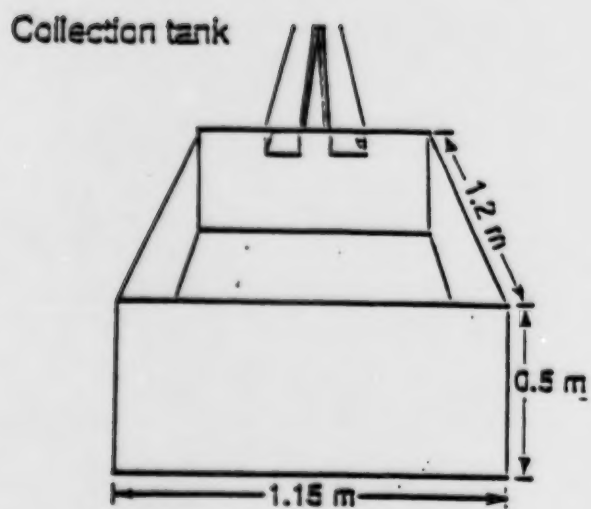


Figure 3.8a: Dimensions of collecting tank.

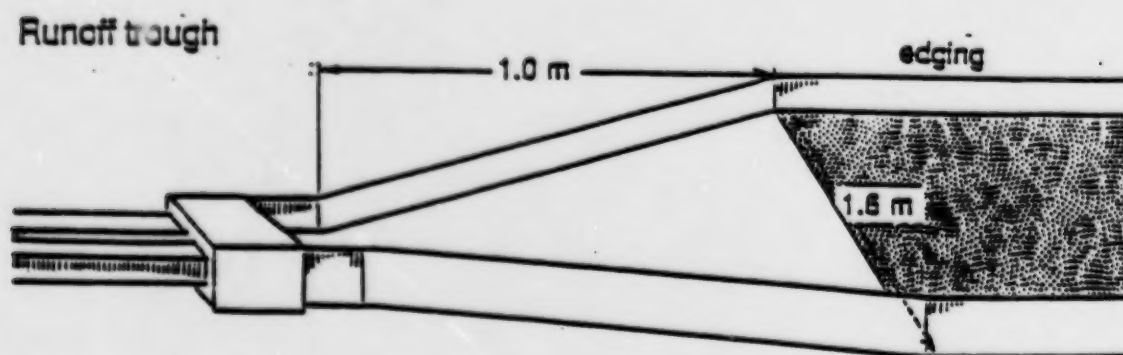


Figure 3.8b: Diagram of split runoff collectors.

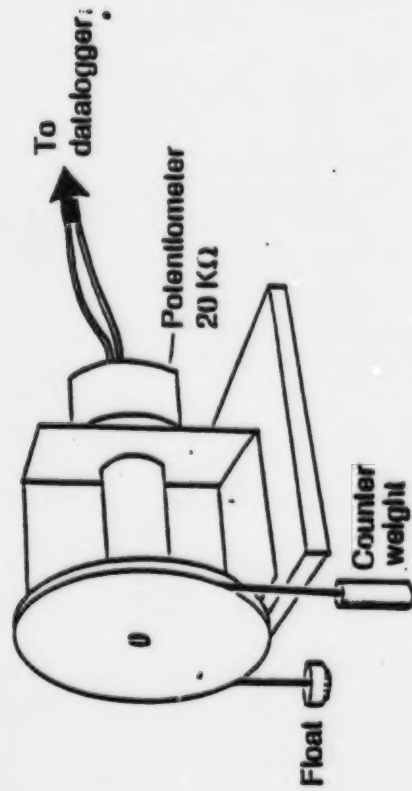


Figure 3.9: Automatic float gauge design for natural precipitation event monitoring.

scale output (5v) can be easily changed by changing the potentiometer (approx. \$30.00) from the current 3 revolution full scale model to a different model (1 revolution, 5 revolution, 10 revolution - full scale), or by changing the diameter of the float pulley. Full part specifications are available on request. A meteorological station was set up to measure rainfall (tipping bucket), temperature and windspeed.

As stated earlier the plots were installed as part of the Ministry of Environment MOE runoff project and were originally scheduled to be moved to a second site in 1989. However, the plots were left in place and were continued to be monitored as part of this SWEEP-TED project. A second set of plots were installed at a second Tillage-2000 site under the MOE project in 1989.

3.7.3 Rainfall Simulation

Twenty-four rainfall simulation plots (1m x 1m) were established in the fall of 1988 (three reps near each of the first eight permanent runoff installations as part of the cooperative study with MOE. The change in surface texture between permanent runoff installation locations, and the similarity in the paired tillage installations points out the necessity of using a paired design in examining runoff characteristics from tillage treatments (i.e. the splitting of soil landscape positions into two tillage treatments).

Rainfall simulation was carried out using the Guelph portable rainfall simulator (GRS II) (Tossell et al. 1987). Two rainfall intensities; (1) low 0.67 mm/min (15 min) and (2) high 2.8 mm/min (10 min), were applied to each plot. Runoff hydrographs were obtained by measuring runoff in 1 minute intervals. All of the sediment was collected for subsequent analysis of particle size distribution and phosphorus. The runoff water was filtered on site during the runoff simulation and the runoff water subsequently analysed for ortho-phosphorus and total phosphorus. The phosphorus analysis was completed by the Land Resource Science Analytical Laboratory under the direction of Earl Gagnon, senior lab manager. The particle size analysis was determined using the pipette method in the Ontario Institute of Pedology soil characterization lab in cooperation with G. Wall, Ag. Canada.

The simulation experiments were repeated in the Spring (April) of 1989, and a modified version once again in June 1989.

3.7.4 Hydraulic Soil Properties

Detailed measurements of surface soil hydraulic properties were carried out at the site under another SWEEP-TED project "Effect of Management on Soil Hydraulic Properties". A summary of that study is given by O'Neill et al. (1990). Results from that study are incorporated into the discussion in this report as needed.

4.0 RESULTS AND DISCUSSION

Instrumentation and installation of the drainage plots was started on October 1, 1988 and finished on March 15, 1989. As stated in the initial project reports, the drought of 1988 and lack of snow cover and precipitation in the spring of 1989 resulted in no recorded tile flow events, until November of 1989. Significant tile flow started in January 1990 and continued through-out the 1990 year.

The main analysis of this report will cover the summary from Nov. 1, 1989 to Jan. 1, 1991. Although the TED project ended in 1991, the sites are continuing to be monitored, sampled, and analysed as part of the Dept. of LRS, Univ. of Guelph research program.

4.1 Tile Flow Quantity

A summary of the daily meteorological measurements for the site are given in Appendix IV. A summary of the daily tile flow measurements are given in Appendix V. The monthly average flow measurements are given in Table 4.1.

From April 1989 to April 1990, tile flow amounted to 10.0 and 14.9 cm of water in the NT and MB systems respectively (Table 4.1). The difference, however, is not significant at the 0.05 probability level. On two of the paired sites the NT was higher, while on the last pair the MB#4 site was higher than NT#5.

In the storm of Jan. 17, 1990, a problem of back pressure in sites 1 and 2 was detected and a new lateral outlet was installed in May, connecting sites 1, 3 and 5 (Fig. 3.2 B), but this modification did not solve the problem completely.

From May 1, 1990 to Oct. 1, 1990 an additional 7.5 cm and 5.5 cm of flow was recorded in the NT and CT treatment. Thus, total recorded flow was 17.5 cm and 20.4 in the NT and MB treatments from Oct. 1989 to Oct. 1, 1990. Total precipitation during this period was 121.0 cm. From October 1 to Dec. 31, 1990 a total of 47.9 cm of rainfall were recorded, with September also having a lot of rain (14.4 cm). The large amount of runoff and drainage water resulting from this excessive rainfall filled the municipal drainage ditch (a total head rise of > 1.5 m) and covered the drainage outlets. This resulted in considerable back pressure in the flow system and the flow measurements during this period Oct. 1 to Dec. 31 are not accurate. The back pressure affected sites #1, site #2, and to some extent site #4. Thus, these flow measurements are not realistic. Average drainage for the year on the remaining sites was 25.9 and 25.4 cm, on the NT (site 5) and MB (site 3 and 6) treatments respectively. Total precipitation for the same period was 149.1 cm, which is well above the average precipitation (approx. 90.0 cm).

Since potential evapotranspiration at the site would be 55 to 60 cm (Brown et al. 1968), the data indicate that considerable water must have

been transported vertically below the tile drain. Thus, the total water and nutrient load leaving the bottom of the root zone can not be estimated very well by only examining the tile flow amounts. The tile water quality can be used as an estimate of the quality of leaching water, but the total load would be greatly underestimated.

4.2 Drainage Water Quality

A summary of the average daily $\text{NO}_3\text{-N}$ concentrations (mg-N/l) for the drainage tile water samples are given in Appendix VI. Each daily value is an average of four samples taken every six hours. Approximately 4000 $\text{NO}_3\text{-N}$ analyses were completed in 1990. The $\text{NO}_3\text{-N}$ concentrations in the municipal drain are also given in Appendix VI. Ortho-phosphorus and total phosphorus analyses of the drainage water were also carried out but values were consistently $<0.01 \text{ mg P/l}$. It is concluded that P loss is negligible in both tillage systems at this site.

The $\text{NO}_3\text{-N}$ concentrations for the different replications are shown as a function of sampling date (Jan. 1, 1990 to Dec. 31, 1990) in Figure 4.1 and Figure 4.2 for the no-till (NT) and moldboard plow (MB) treatments respectively. The average concentration across all replications is shown in Figure 4.3 for both tillage systems. The yearly average concentration was $10.7 \text{ (mg } \text{NO}_3\text{-N/l)}$ for both tillage systems. The average $\text{NO}_3\text{-N}$ concentrations exceeded the drinking water standard (10 mg N/l) value. In contrast, the average $\text{NO}_3\text{-N}$ concentration in the municipal drain water was approximately 4.0 (mg N/l) (Figure 4.4).

The data suggest no significant differences in the average (yearly) $\text{NO}_3\text{-N}$ concentrations between tillage systems. However, the concentrations were significantly higher in the NT treatment in the early spring to early summer period (day 50 to day 200). The CT treatment tended to be higher in the fall period. As stated earlier the flow data are less reliable in the fall period.

4.3 Tile Nitrate Load

The amount of $\text{NO}_3\text{-N}$ (kg N/ha) exiting the site by tile flow was calculated by combining the flow quantity and $\text{NO}_3\text{-N}$ concentration data. The 6 hour $\text{NO}_3\text{-N}$ concentration data was linearly interpolated to give one hour estimated $\text{NO}_3\text{-N}$ values which were then multiplied by the total hourly flow to give $\text{kg } \text{NO}_3\text{-N/ha}$. A summary of daily and cumulative load estimates are given in Appendix VII. The monthly total loads are given in Table 4.2.

Table 4.1 Total monthly tile flow.

Tile Drain Flow												
Date	Pair #1 (1.6)		Pair #2 (2.3)		Pair #3 (5.4)		Average					
	1 NT	6 MB	2 NT	3 MB	5 NT	4 MB	NT	MB	NT	MB	Δ (NT-MB)	
----- cm/month -----												
April-Oct. 1989	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
Oct. 1989	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	
Nov. 1989	0.4	0.4	0.0	0.0	0.2	1.1	0.20	0.50	0.20	0.50	-0.30	
Dec. 1989	0.0	0.0	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	0.0	
Jan. 1990	11.2	1.9	8.7	8.2	1.0	5.2	6.70	5.10	6.70	5.10	+1.66	
Feb. 1990	0.2	0.8	0.2	0.2	0.6	0.6	0.33	0.4	0.33	0.4	-0.13	
March 1990	3.6	2.0	0.0	0.2	1.6	15.1	1.73	5.77	1.73	5.77	-4.04	
April 1990	1.2	0.0	0.0	0.0	1.0	8.9	0.73	3.0	0.73	3.0	-2.27	
Sub-total	16.6	5.1	8.9	8.6	4.4	30.9	10.0	14.9	10.0	14.9	-4.9	
May 1990	0.4	0.0	0.0	0.0	6.3	10.0	2.2	3.3	2.2	3.3	-1.1	
June 1990	5.5	1.1	0.0	0.2	0.5	1.1	2.0	0.8	2.0	0.8	1.2	
July 1990	0.5	1.5	0.0	0.0	0.1	0.1	0.2	0.53	0.2	0.53	-0.33	
Aug. 1990	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
Sept. 1990	9.2	0.0	0.0	0.0	0.1	2.8	3.1	0.93	3.1	0.93	2.2	
Oct. 1990*	35.2	0.0	47.8	6.1	3.9	14.4	29.0	6.8	29.0	6.8	22.1	
Nov. 1990*	38.6	0.0	51.7	8.1	4.1	28.3	31.5	12.1	31.5	12.1	19.3	
Dec. 1990*	28.1	6.7	46.0	13.4	6.4	32.9	26.8	17.7	26.8	17.7	9.1	
TOTAL	134.1	14.3	154.7	36.5	25.9	120.6	104.9	57.1	104.9	57.1	47.8	

*Exceeded flow capacity of measurement system at site 1, 2 and 4.

From April 1, 1989 to April 1, 1990 total $\text{NO}_3\text{-N}$ loss through the tile lines was 12.2 kg N/ha and 10.8 kg N/ha from the NT and CT treatments respectively. The average flow weighted $\text{NO}_3\text{-N}$ concentration for this period (using Table 4.2 and Table 4.1) was 12.2 (mg $\text{NO}_3\text{-N/ha}$) and 7.3 mg $\text{NO}_3\text{-N/ha}$ for the NT and CT treatment respectively. Thus, the nitrate flux weighted concentrations were considerably higher in the NT treatments (significant at 0.05 probability).

From April 1, 1989 to Oct. 1, 1990 the total $\text{NO}_3\text{-N}$ loss through the tile line was 21.2 kg N/ha and 15.83 kg N/ha in the NT and CT treatments respectively. The overall flux weighted concentration from Nov. 1989 to Oct. 1, 1990 was 12.1 ppm and 7.8 ppm respectively, again significantly higher in the NT. The $\text{NO}_3\text{-N}$ flux was significantly higher in the Oct. to Dec. 1990 period because of the high flows. Again, there may be errors in estimating flow because of back pressure. The flux concentration (Oct. to Dec. 1990) for the NT#5 site which was not affected by back pressure was 9.3 (mg $\text{NO}_3\text{-N/l}$) compared to 15.4 and 10.9 for MB#3 and MB#6 (Table 4.2). Thus, the $\text{NO}_3\text{-N}$ flux weighted concentrations were considerably higher in the MB compared to NT treatment during this period.

Total $\text{NO}_3\text{-N}$ loading from Oct. 1, 1989 to Sept. 31, 1990 was 21.2 kg $\text{NO}_3\text{-N/ha}$ and 15.8 kg $\text{NO}_3\text{-N/ha}$ for the NT and MB systems respectively. Thus, the NT appear to have about 34% higher $\text{NO}_3\text{-N}$ losses than the MB site. Total $\text{NO}_3\text{-N}$ loss for the entire monitoring period (Nov. 1, 1989 to Dec. 31, 1990) was 106.2 kg $\text{NO}_3\text{-N/ha}$ and 57.5 kg $\text{NO}_3\text{-N/ha}$ for the NT and MB sites respectively. However, the losses from Oct. 1, 1990 (start of significant tile flow in 1990) to Dec. 31, 1990 are probably associated with the 1990 cropping season (not the 1989) and may be subject to considerable error because of back pressure and flow calculation errors.

4.4 Groundwater Quality

A summary of the $\text{NO}_3\text{-N}$ concentrations in the groundwater as a function of depth from the soil surface is given in Appendix VIII. These values were obtained from the six multilevel samplers in each of the tillage treatments (ie 2 per tillage replication). Chloride analysis of these samples are also given in Appendix VIII.

Daily Nitrate Concentration - No Tillage Plots

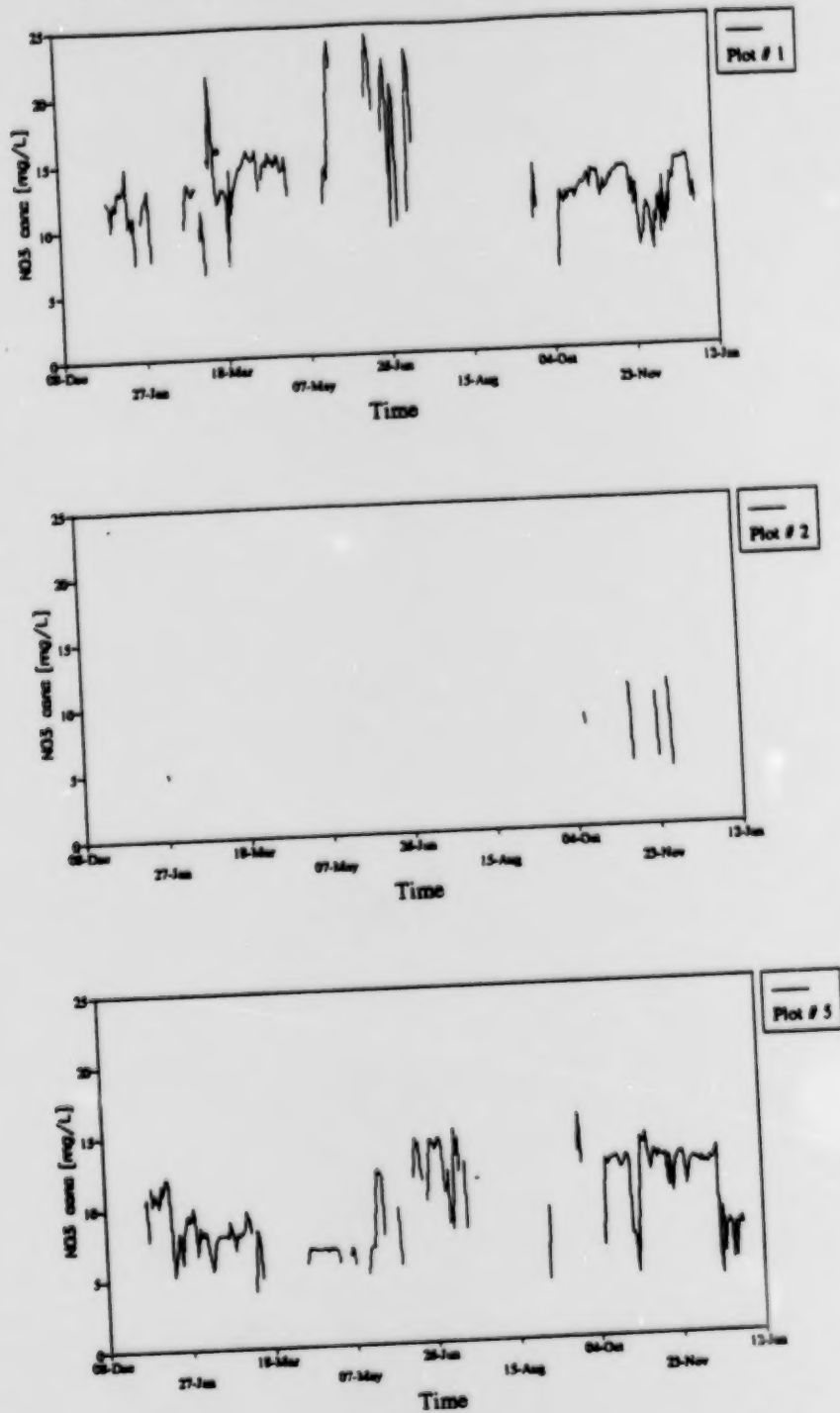


Figure 4.1: Nitrate nitrogen concentrations versus sampling date during 1990, for the no-till plots.

Daily Nitrate Concentration - Conventional Tillage Plots

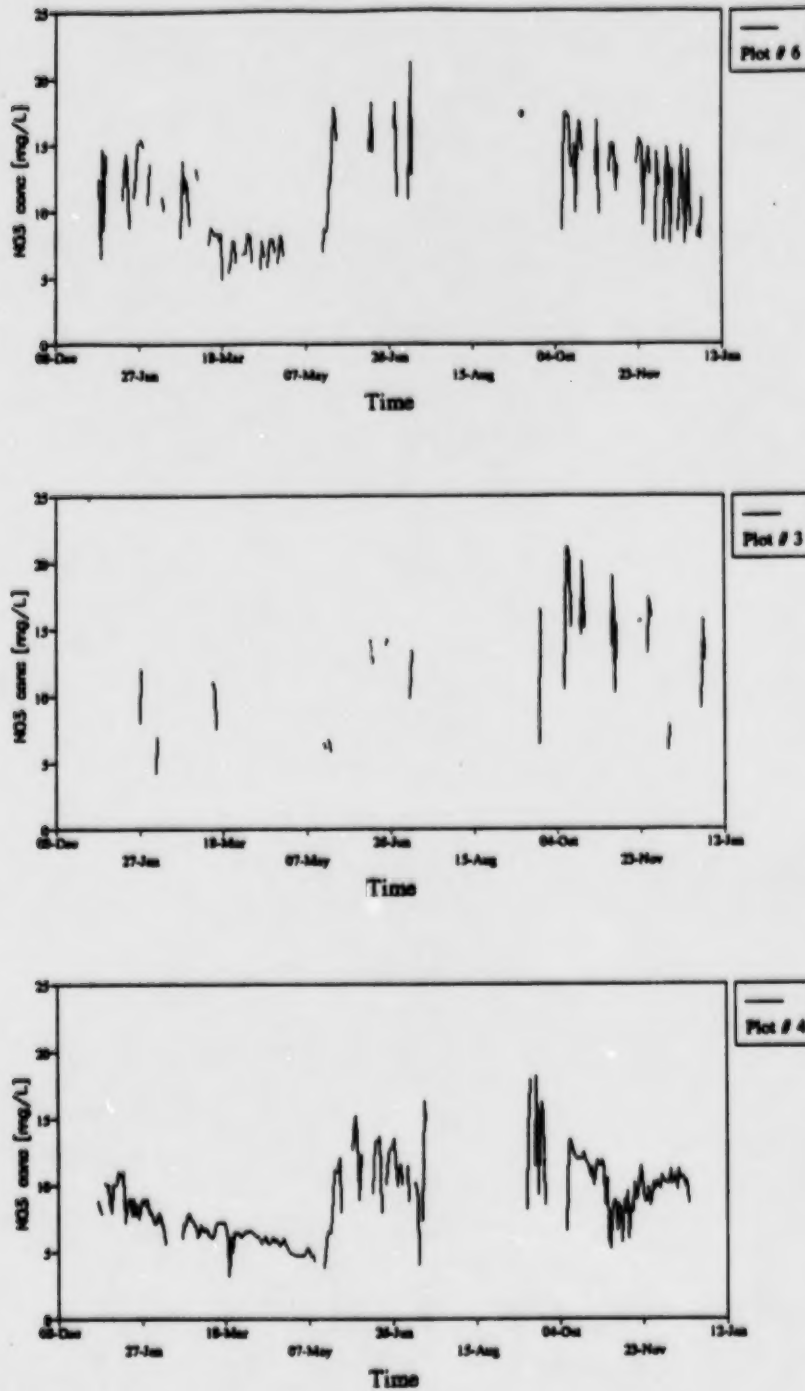


Figure 4.2: Nitrate nitrogen concentrations versus sampling date during 1990, for the moldboard plots.

Average Nitrate Concentration (Daily)

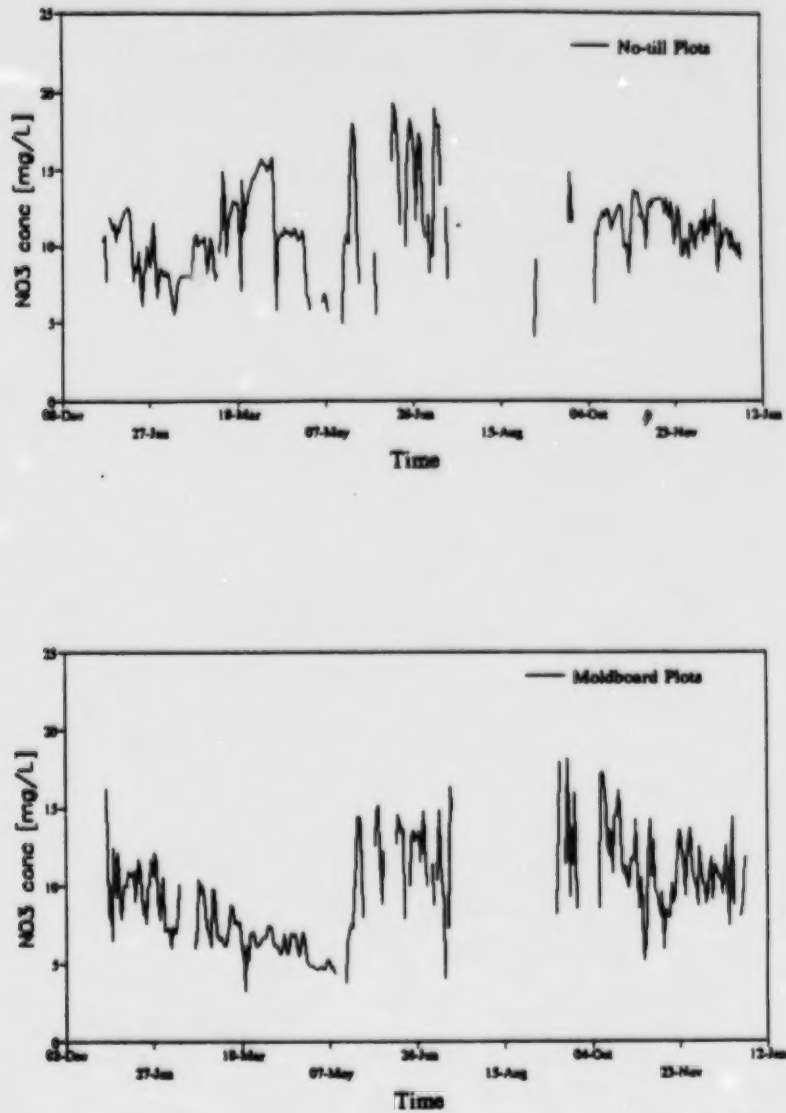


Figure 4.3: Average nitrate nitrogen concentrations versus sampling date during 1990, for both tillage treatments

Drainage Experiment 1989/90
Nitrate Conc. at River

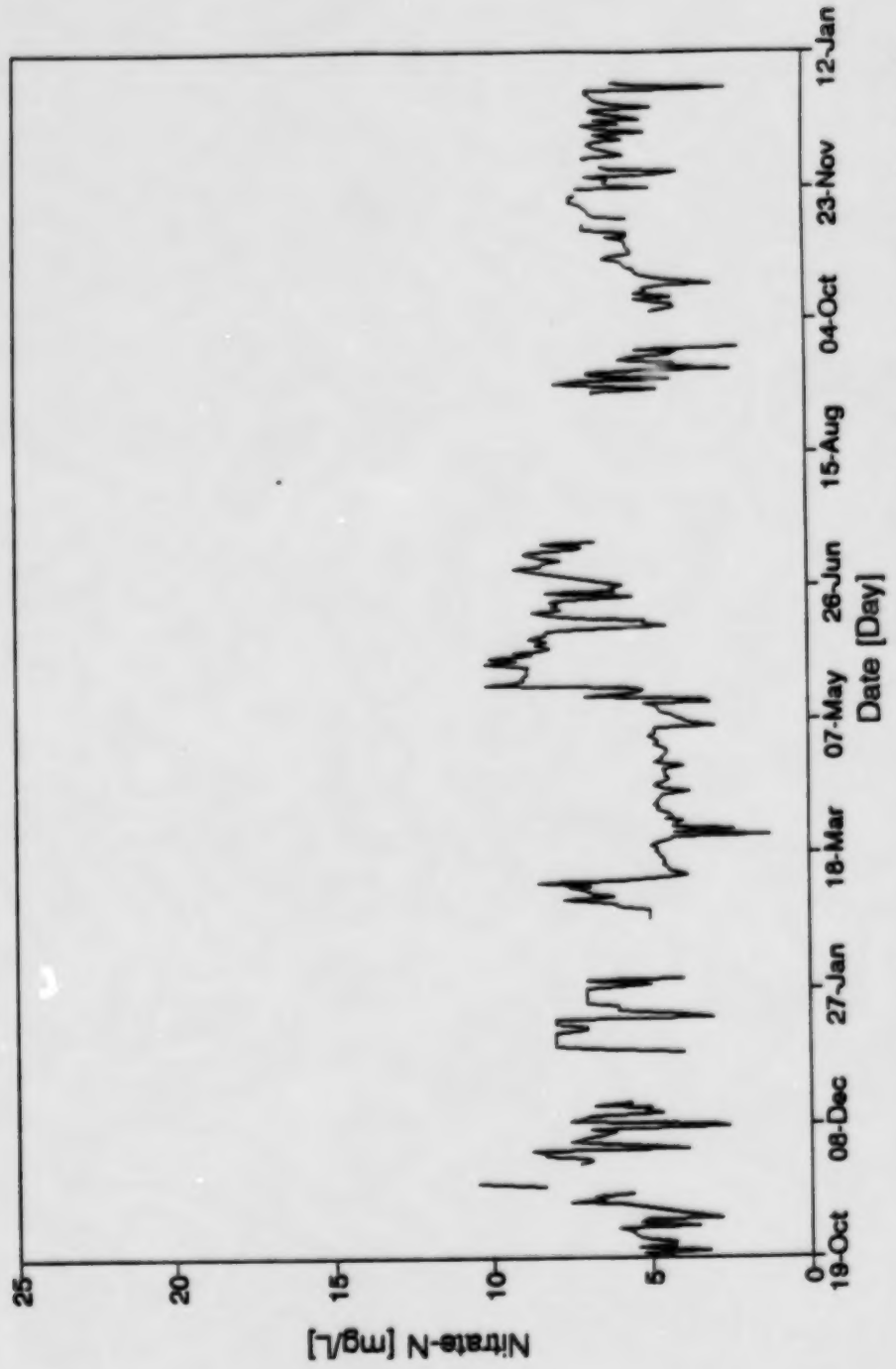


Table 4.2 Total monthly nitrate nitrogen loading in the tile flow.

Nitrate Loading In Tile Flow													
Date	MT	MR	NT	MR	NT	MR	NT	MR	NT	MR	NT	Average	A
-----kg NO ₃ -N ha month-----													
April-Oct. 1989	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00
Nov. 1989	0.4	0.4	0.0	0.0	0.2	0.1	0.1	0.20	0.1	0.20	0.5	0.00	0.00
Dec. 1989	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00	0.00	0.00
Jan. 1990	15.0	2.0	10.0	7.0	1.0	4.0	4.0	9.0	4.0	9.0	4.0	5.0	5.0
Feb. 1990	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.33	-0.33	-0.33
March 1990	5.0	2.0	0.0	0.0	1.0	10.0	2.0	4.0	2.0	4.0	4.0	-2.00	-2.00
April 1990	2.0	0.0	0.0	0.0	1.0	5.0	1.0	2.0	1.0	2.0	2.0	-1.00	-1.00
Sub-total	22.4	5.4	10.0	7.0	3.2	19.1	12.2	10.83	1.4	10.83	1.4	1.4	1.4
May 1990	1.0	0.0	0.0	0.0	4.0	7.0	1.7	2.3	0.6	2.3	1.0	3.0	3.0
June 1990	11.0	2.0	0.0	0.0	1.0	1.0	4.0	1.0	3.0	4.0	1.0	-0.7	-0.7
July 1990	1.0	3.0	0.0	0.0	0.0	0.0	0.3	1.0	0.0	0.3	1.0	0.0	0.0
Aug. 1990	0.0	0.0	0.0	0.0	0.0	0.0	3.0	0.7	15.3	3.0	0.7	15.3	15.3
Sept. 1990	9.0	0.0	0.0	0.0	0.0	2.0	25.0	9.7	22.0	25.0	9.7	22.0	22.0
Oct. 1990*	36.0	0.0	35.0	13.0	4.0	16.0	34.7	12.7	9.3	34.7	12.7	9.3	9.3
Nov. 1990*	41.0	0.0	58.0	12.0	5.0	26.0	28.3	19.0	48.7	28.3	19.0	48.7	48.7
Dec. 1990*	32.0	6.0	48.0	17.0	5.0	34.0	10.1	11.1	1.1	10.1	11.1	1.1	1.1
TOTAL	153.4	15.4	150.0	50.0	23.2	106.1	106.2	57.5	1.1	106.2	57.5	1.1	1.1
Average Flux NO ₃ -N Concentration (mg N/l)	10.3	11.2	8.9	10.8	13.7	8.9	10.1	11.1	1.1	10.1	11.1	1.1	1.1

*Flow on sites #1, #2, and #4 are not reliable for these months.

The average $\text{NO}_3\text{-N}$ concentration in the groundwater (1m to 5m depth) on Nov. 15, 1990 was 10.4 (mg N/l) and 11.4 (mg N/l) in the NT and MB treatment respectively (Table 4.3). This difference is largely due to higher concentrations near the surface of the water table. These average values are almost exactly the same as the overall flux averaged $\text{NO}_3\text{-N}$ concentrations measured in the tile flow (ie 10.1 and 11.1 mg N/l in the NT and MB respectively - Table 4.2). The graphs of average $\text{NO}_3\text{-N}$ concentration versus sample depth indicates a sharp increase in concentration above the 2.5 m depth in both tillage systems (Figure 4.5). The NT treatment shows a peak concentration of 14.5 (mg N/l) at 1.9 m, with the concentration decreasing at shallower and deeper depths in the groundwater. The MB treatment shows a different depth distribution, with concentrations averaging 13.5 (mg N/l) over the entire 1.0 m-2.5 m depth. The average concentration at the 1.0 m (shallowest) depth was 7.2 (mg N/l) and 12.4 (mg N/l) for the NT and MB treatment respectively. The concentrations below 2.5 m average around 10.0 (mg N/l) for both treatments, with the MB treatment slightly higher. The concentration below 2.5 m is very similar to tile water average over the 1990 monitoring year. The range in tile water $\text{NO}_3\text{-N}$ values (5-20 mg N/l) is also similar to the range in values for this single time sampling of the groundwater.

The multilevel groundwater samples were taken on Nov. 15, 1990, approximately a year after the application of the field-scale chloride pulse (applied Nov. 1, 1989). The groundwater samples from Nov. 15, 1990 were analysed for chloride to determine how far down the chloride had travelled in the previous year. The graph of chloride concentration versus depth in the groundwater for paired sites #1 (NT) and #6 (MB) is given in Figure 4.6(a). The chloride concentrations show a distinct bulge in the upper 1.5-2.0 m of the groundwater which must be from the pulse application on Nov. 1, 1989. The chloride plume in the MB #6 site is centred at about 1.4 m while the NT #1 plume is centred at 1.7 m. Thus, the chloride appears to have moved about 21% faster in the NT treatment. The nitrate-N concentrations for these sites follow almost an identical pattern, but the N pulse is centred slightly deeper than the chloride (Figure 4.6(b)). Nitrogen was not applied with the chloride and, this pulse of N is assumed to be related to the leaching of the soil residual-N that was near the soil surface the previous year.

The chloride data for the paired sites #2 (NT) and #3 (MB) show even more distinct chloride concentration increases (Figure 4.7(a)), but the average solute travel times seem to be similar in both treatments (ie the average travel depth associated with the centre of the chloride plume is the same in each treatment). The nitrate data from these sites also show a distinct increase in the region of the chloride plume for the MB #3 treatment (Figure 4.7b). The NT #2 values show a slight increase but not as pronounced as in the MB #3 site. The chloride data from the paired

CLINTON PIEZOMETER READINGS
NITRATE - NOV. 15, 1990 - TILLAGE Avg.

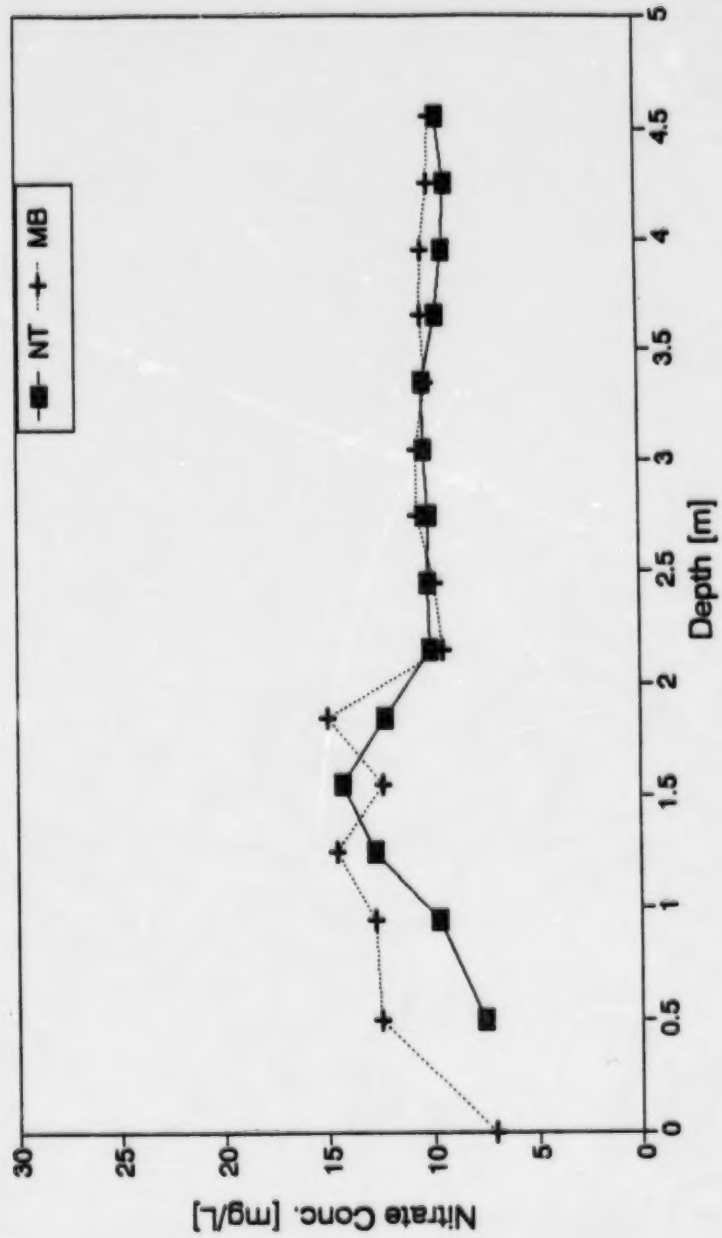


Figure 4.5: Average Nitrate nitrogen concentrations in the groundwater versus depth for both tillage treatments.

CLINTON PIEZOMETER READINGS
CHLORIDE - NOV. 15, 1990 - SITE #1, 6

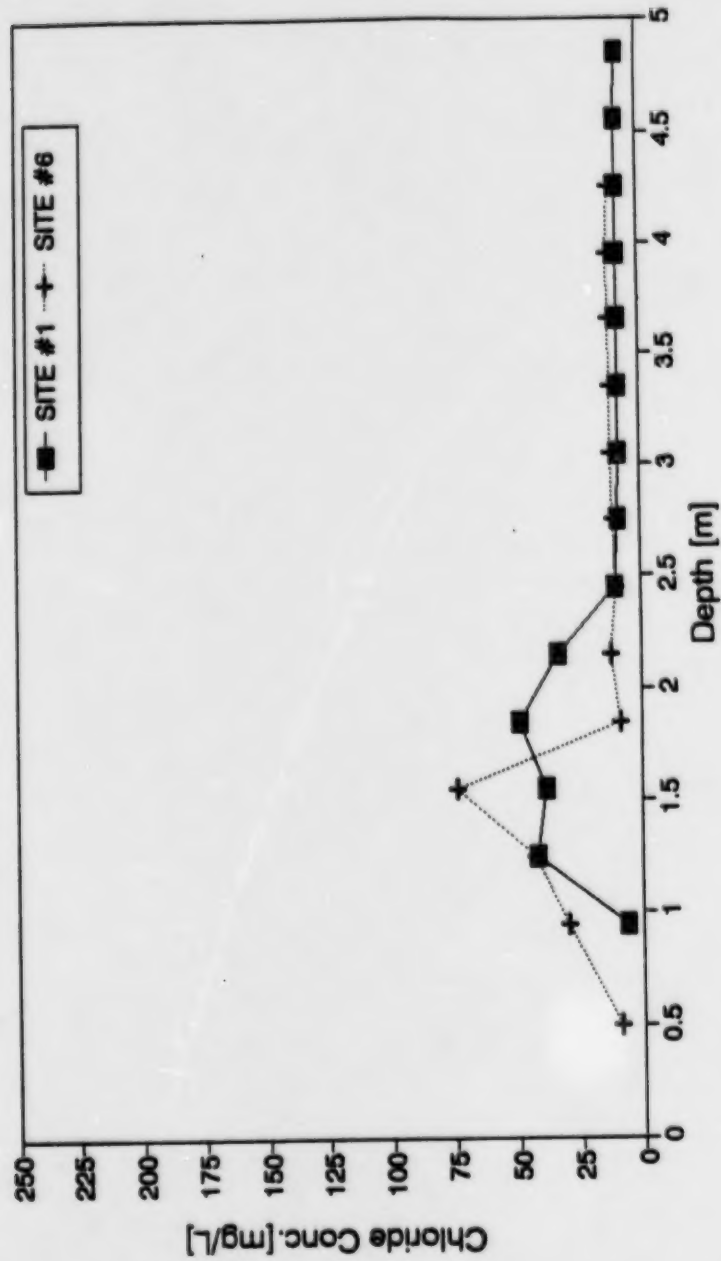


Figure 4.6(a): Chloride concentrations in the groundwater versus depth for site #1 (NT) and site #6 (MB) .

CLINTON PIEZOMETER READINGS
NITRATE - NOV. 15, 1990 - SITE #1, 6

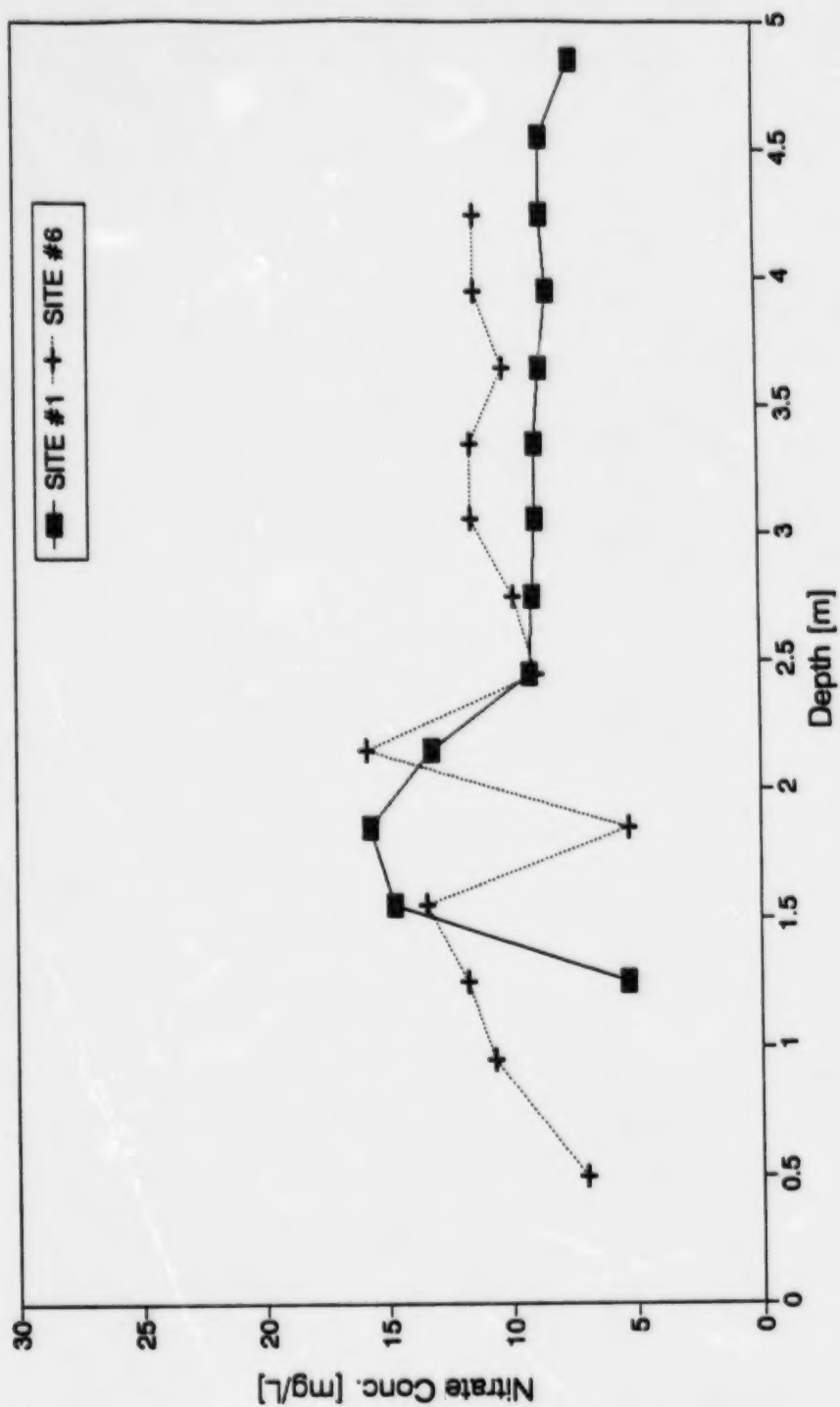


Figure 4.6(b): Nitrate concentration in the groundwater versus depth for site #1 (NT) and site #6 (MB).

CLINTON PIEZOMETER READINGS
CHLORIDE - NOV. 15, 1990 - SITE #2, 3

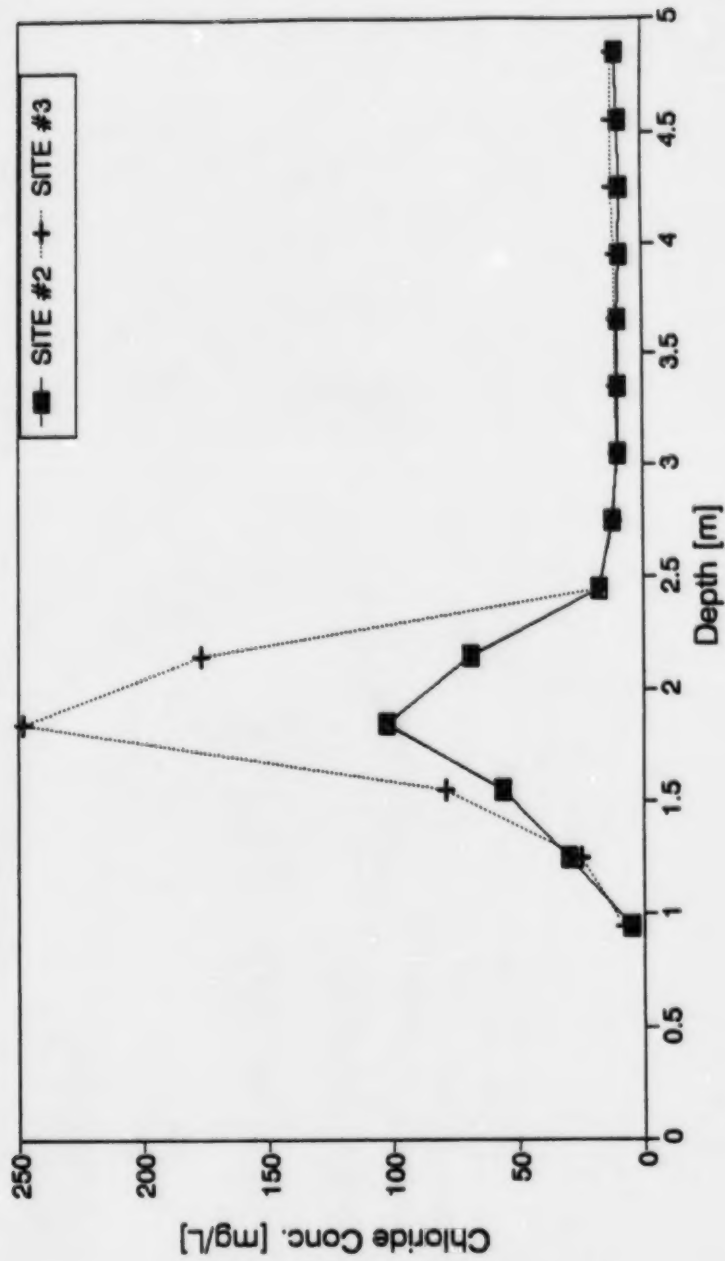


Figure 4.7(a): Chloride concentrations in the groundwater versus depth

for site #2 (NT) and site #3 (MB).

CLINTON PIEZOMETER READINGS
NITRATE - NOV. 15, 1990 - SITE #2, 3

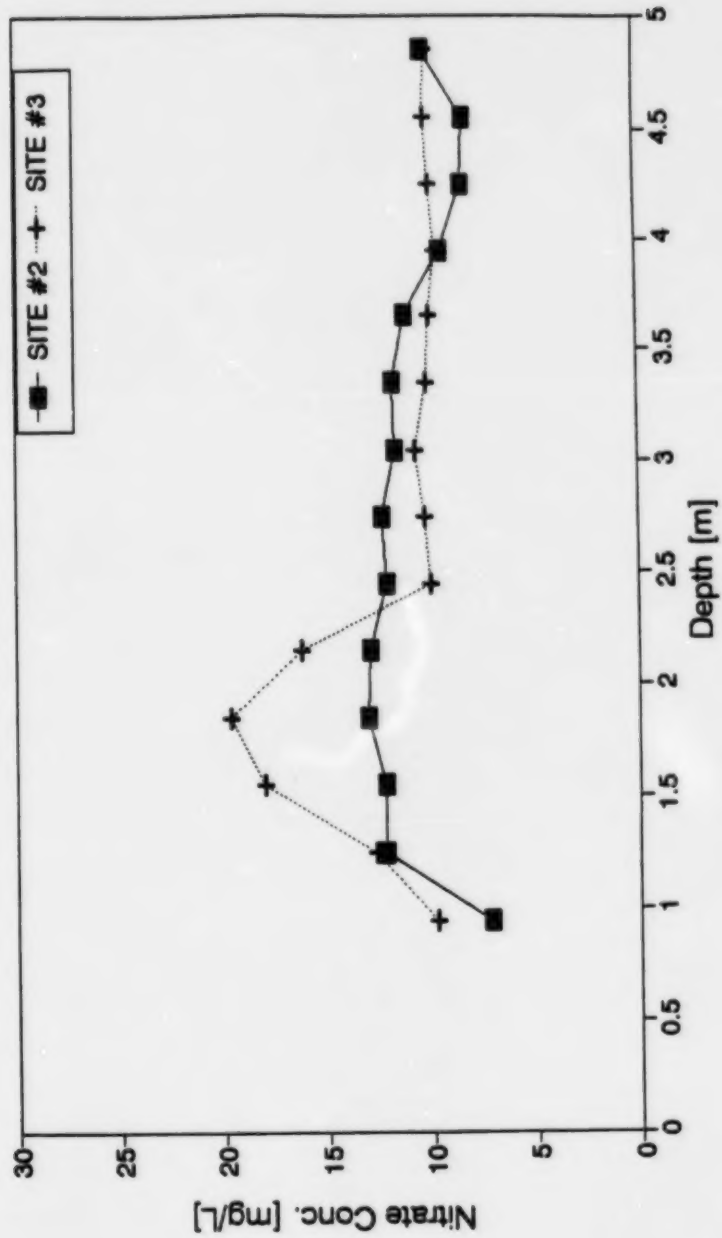


Figure 4.7(b): Nitrate concentrations in the groundwater versus depth for site #2 (NT) and site #3 (MB).

CLINTON PIEZOMETER READINGS
CHLORIDE - NOV. 15, 1990 - SITE #4, 5

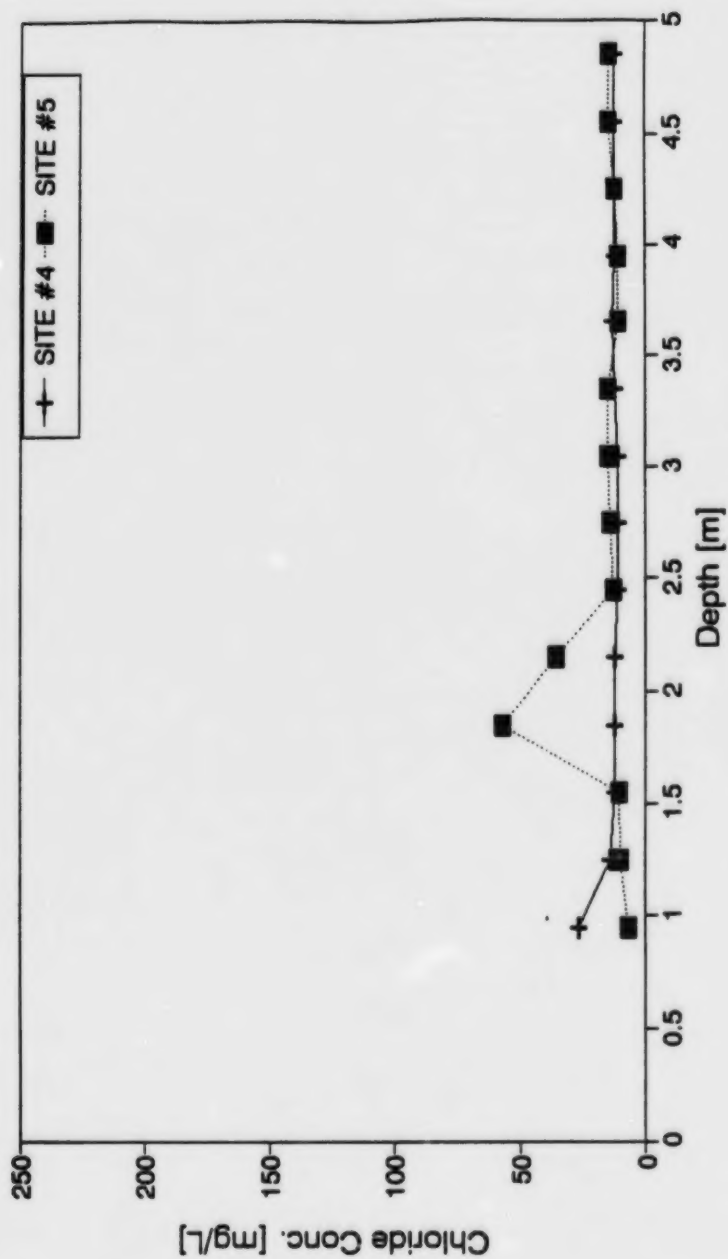


Figure 4.8(a): Chloride concentrations in the groundwater versus depth for site #5 (NT) and site #4 (MB).

CLINTON PIEZOMETER READINGS
NITRATE - NOV. 15, 1990 - SITE #4, 5

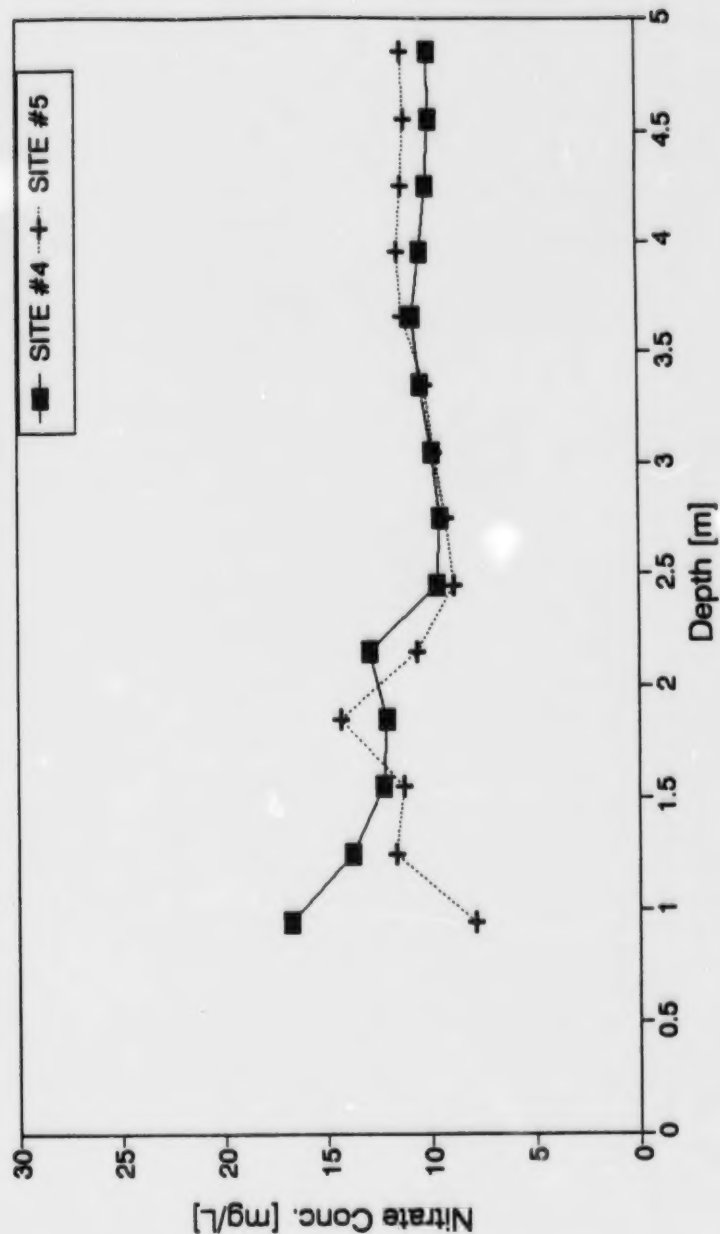


Figure 4.8(b): Nitrate concentrations in the groundwater versus depth for site #5 (NT) and site #4 (MB).

Table 4.3: Average nitrate-N concentrations from the multi-level groundwater samplers in the NT and CT plots on Nov. 15, 1990.

Depth (m)	NO ₃ -N Concentration Tillage System		
	CT	NT	Y(CT-NT)
	-----mg NO ₃ -N/l-----		
1.0	12.4	7.3	5.1
1.3	12.7	9.7	3.1
1.6	14.6	12.7	1.9
1.9	12.4	14.3	-1.9
2.2	15.0	12.2	2.8
2.5	9.5	10.1	-0.6
2.8	9.7	10.2	-0.5
3.1	10.7	10.2	0.5
3.4	10.7	10.3	0.4
3.7	10.3	10.4	-0.1
4.0	10.5	9.8	0.7
4.3	10.4	9.4	1.0
4.6	10.0	9.3	0.7
4.9	10.0	9.6	0.4
Avg.	10.39 [*]	11.35 [*]	0.96

Significantly different (t=2.1) at 0.05 probability.

sites #4 (MB) and #5 (NT) show less distinct chloride increases (Figure 4.8a). The NT #5 site has a definite increase centred at 1.8 m, which is similar to the other NT sites, but the MB treatment has no increase except a moderate rise in concentration at the shallowest sampling depth (1.0 m). This suggests the pulse has either moved laterally off the site, or has exited out the tile lines. The nitrate values show similar depth distribution to the other sites (Figure 4.8b)

In general the chloride and nitrate concentration in the multilevels suggest a more narrowly concentrated pulse of chloride has moved through the NT compared to the MB and the pulse has moved slightly faster in the NT. This is consistent with the higher $\text{NO}_3\text{-N}$ concentration in the NT treatment tile flow in the spring of 1990 and the subsequently higher concentrations in the MB in the fall of 1990. The depth of the chloride pulse (1.9 m) is also consistent with the drainage flow estimates and the conclusion that considerable movement of water must be occurring vertically below the tile lines which are at approximately 0.75 m depth. With a porosity of $0.43 \text{ m}^3\text{m}^{-3}$ (bulk density = 1.5 g cm^{-3}) a total of approximately 49 cm of water must have moved below the tile line.

Total precipitation from Oct. 1, 1989 to Oct. 1, 1990 was 121.0 cm. Average tile drainage was approx. 19.0 cm over the same period. If 49.0 cm of water leaked below the tile line, then about 53 cm of water must have evapo-transpired. Average potential evapotranspiration for the site is 61.0 cm (Brown et al. 1968), so the estimates seem reasonable.

The flux averaged $\text{NO}_3\text{-N}$ concentration from Oct. 1, 1989 to Oct. 1, 1990 was 7.8 and 12.1 mg $\text{NO}_3\text{-N/l}$ for the MB and NT treatments respectively. Assuming this is also the fluxed averaged $\text{NO}_3\text{-N}$ concentration in water leaking past the tile line, an estimated 38.2 kg N/ha and 59.3 kg N/ha leaked past the tile lines in the MB and NT system respectively. Adding the measured tile loss of $\text{NO}_3\text{-N}$ to the leakage loss gives 54.0 and 80.5 kg $\text{NO}_3\text{-N/ha}$ total nitrogen loss from MB and NT treatments respectively.

The presence of a Nitrate-N bulge in the groundwater which coincides with the chloride pulse was not intuitively expected. However, the similarities can be explained by the distribution of $\text{NO}_3\text{-N}$ in the soil profile in the fall of 1989 when the pulse was applied. A summary of all of the soil sampling analysis for both chloride and nitrate concentrations is given in Appendix IX. The average concentration of $\text{NO}_3\text{-N}$ ($\mu\text{g/g}$ soil) as a function of soil depth (both tillage systems) for the top 1.0 m is shown for October 12, 1989 and Nov. 21, 1989 in Figure 4.9. The chloride pulse was applied on Nov. 1, 1989, approximately between the two sampling dates for $\text{NO}_3\text{-N}$. As indicated in Figure 4.9, a large amount of $\text{NO}_3\text{-N}$

Average soil nitrate at two dates

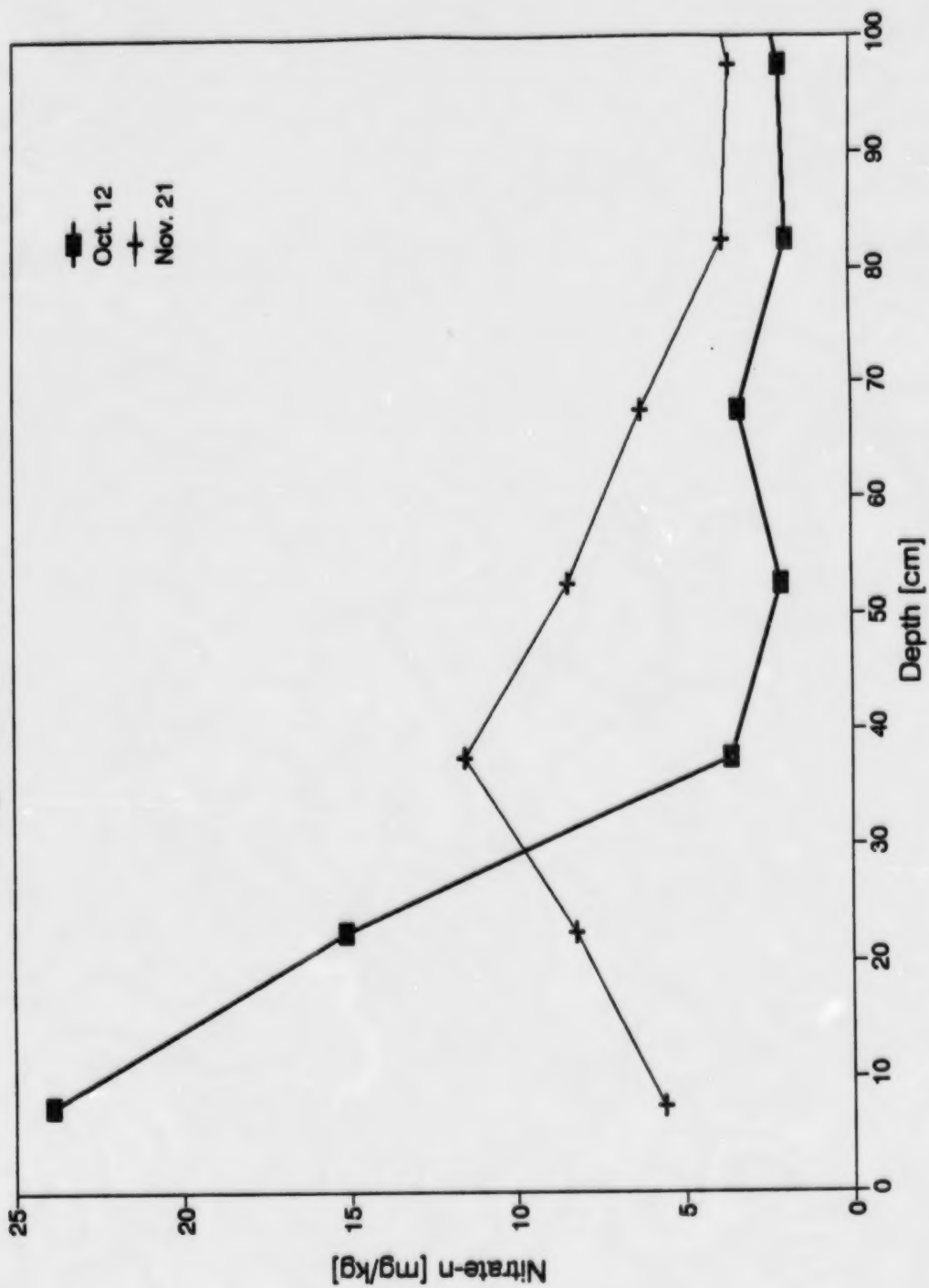


Figure 4.9: Soil nitrate (averaged across tillage treatments) versus soil depth on Oct. 12 and Nov. 21, 1989.

Comparison of Nitrate and Chloride
distribution on Nov. 21, 1989

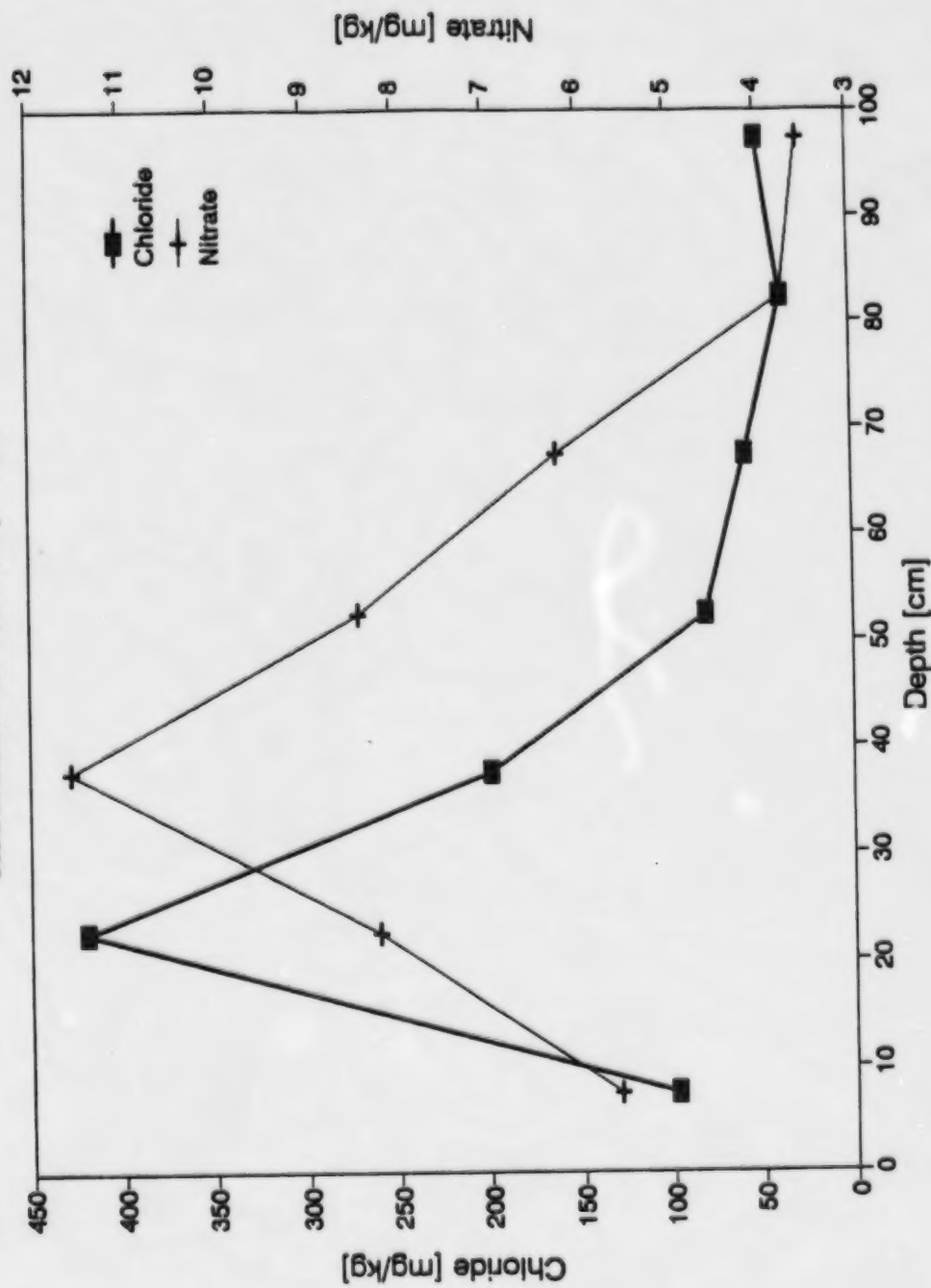


Figure 4.10: Comparison of soil nitrate and chloride distribution with depth
16 days after Cl pulse application.

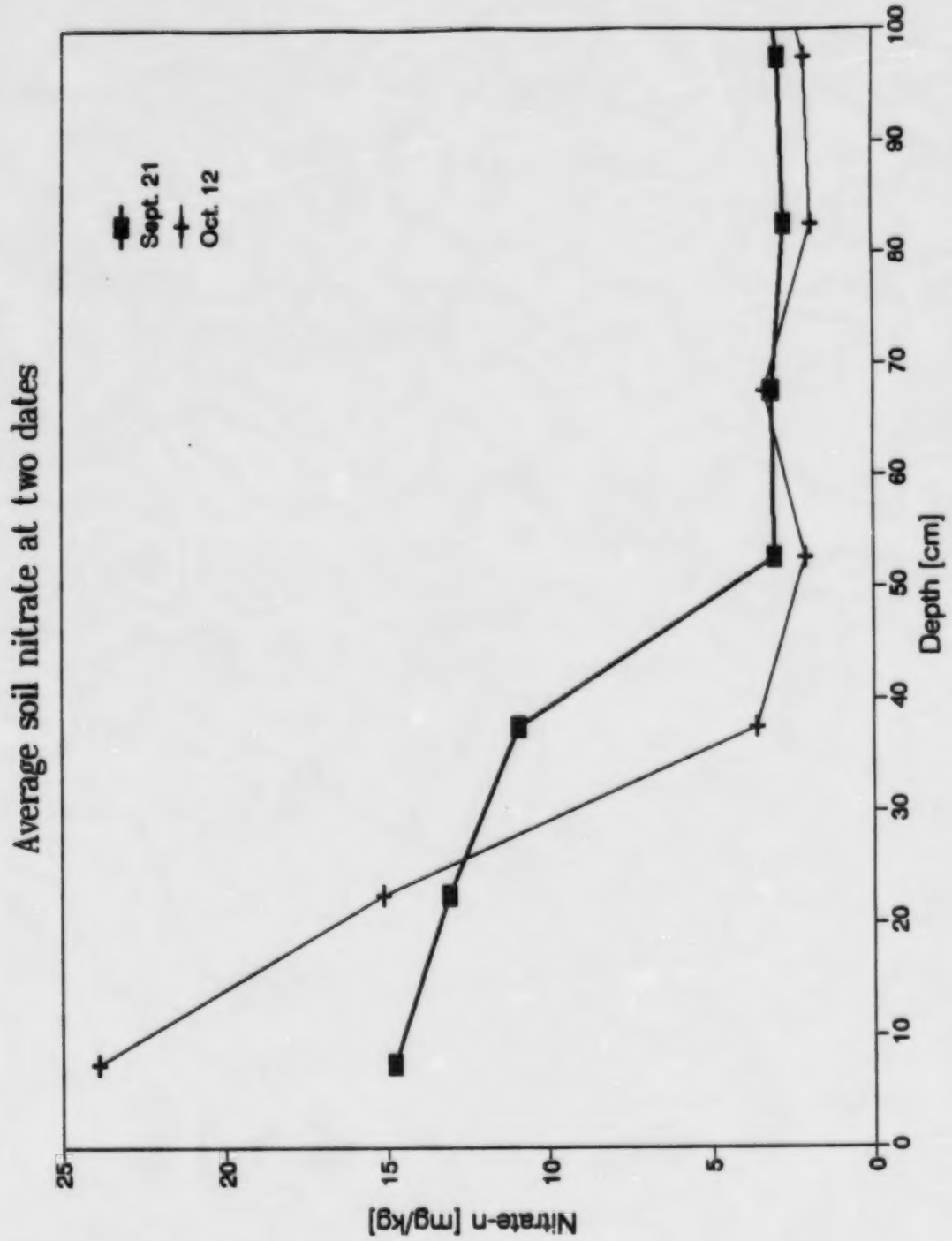


Figure 4.11: Soil Nitrate (averaged across tillage treatments) versus soil depth

(approximately 80 kg N/ha) was present in the top 0-0.3 m depth on Oct. 12, 1989. Much lower amounts were present below that (approximately 10 kg N/ha for every 0.3 m depth increment). The Nov. 21 data indicate $\text{NO}_3\text{-N}$ transport due to fall rains and the movement of a pulse of nitrate into the soil. The pulse of $\text{NO}_3\text{-N}$ is associated with the high accumulated $\text{NO}_3\text{-N}$ in the soil surface and its subsequent leaching by fall rains. Fortunately the chloride pulse was applied to the soil surface at about the same time as the fall leaching event started. Thus, the chloride should be expected to behave in a manner similar to the nitrate in the top of the soil profile. This explains the similarity in the $\text{NO}_3\text{-N}$ pulse and chloride pulse found in the multilevel samplers a year later. It also confirms a significant flux of residual $\text{NO}_3\text{-N}$ in the fall period to the groundwater table.

Further evidence of the similarity in the nitrate and chloride fluxes is evident from a comparison of the depth distribution of chloride and nitrate from the Nov. 21, 1989 soil sampling (Figure 4.10). The chloride pulse has travelled to an average depth of approximately 0.20 m since it was applied, with the peak concentration at 0.25 m. The nitrate pulse is centred at about 0.36 m, just slightly ahead of the chloride, which is expected since the nitrate was distributed deeper initially, and would also have been subject to leaching between Oct. 12 and Nov. 1 (period between 1st Nitrate sampling and date of chloride application). Little leaching of Nitrate occurred before Oct. 12, 1989 as indicated in a comparison of soil nitrate profiles from Sept. 21 and Oct. 12 (Figure 4.11). During this period Nitrate-N accumulated in the surface 0-25 m with little change occurring below 0.35 m. Also, tile flow at the site did not start until Nov. 15.

The data suggest that the chloride pulse applied on Nov. 1, 1989 should be a good tracer for the bulk of the residual $\text{NO}_3\text{-N}$ left in the soil in the fall of 1989.

4.5 Soil Nitrogen Sampling

The total $\text{NO}_3\text{-N}$ (kg N/ha) in the 0-0.6 m depth for the different tillage treatments is summarized in Table 4.4. As expected the amount of N in the soil varies considerably during the year. However, the values of total $\text{NO}_3\text{-N}$ (kg N/ha) in the top 0-0.6 m at time of planting (early to mid-May) did not vary significantly over the 3 years of measurement. The NT average was 71.0, 76.0, and 81.0 (kg $\text{NO}_3\text{-N/ha}$) for 1989, 1990, and 1991 respectively. the MB values were 56.0, 67.0, and 71.0 for the same sampling years. These values are equivalent to the new N soil test value and are quite similar considering the range in climate and preceding crops (Table 3.2). The N test values suggest an average recommended N fertilizer rate of 85 kg N/ha and 115 kg N/ha for the NT and MB treatments respectively, for the 1989 corn crop (Price ratio = 5.0). The total

amount of fertilizer N applied in 1989 was 162.0 kg N/ha (Table 3.2). Thus, the average predicted amount of excess fertilizer nitrogen applied to the soil was 77.0 and 46.0 kg N/ha for the 1989 cropping year, for the NT and MB treatments respectively. This is very similar to the 80.5 and 54 kg $\text{NO}_3\text{-N}$ /ha losses for the NT and MB respectively, measured from the tile flow and deep leakage flow estimate.

The soil data also indicate the significant mineralization potential of the soils from this site. The soil $\text{NO}_3\text{-N}$ increased by 30-40 kg N/ha from early April to early May in both the 1989 and 1990 spring periods. In 1991 the May soil $\text{NO}_3\text{-N}$ is the highest of all the years even though little fertilizer was applied in 1990 under soybeans. In addition, the Nov. 15, 1990 soil $\text{NO}_3\text{-N}$ is lower than the May 17, 1991 soil $\text{NO}_3\text{-N}$.

The soil N data shows considerable variability, and the high mineralization rate limits the accuracy of estimating $\text{NO}_3\text{-N}$ leaching from the soil data. The high variability comes from the variable deposited material in the soil zone. Pockets of very high organic matter content are scattered within the site horizontally and with depth. The average 1989 fall $\text{NO}_3\text{-N}$ value was estimated by averaging the Sept. 21 to Nov. 21 values. Since no tile flow and little leaching occurred before Nov. 15, the average should be a good estimate for that period. This gave an estimated 138.1 kg N/ha and 115 kg N/ha in the NT and MB sites respectively. If the average soil $\text{NO}_3\text{-N}$ value in the fall of 1989 is matched to the early spring value from 1990, then an estimated 92.0 kg N/ha and 52.0 kg N/ha were lost from the root zone in the NT and MB treatment respectively during the Sept. 1989-May 1990 period. This again is very similar to the total N leaching losses given earlier from the flow and fertilizer excess estimates.

The estimated leaching losses based on the soil data varied considerably from plot to plot, as did the spring soil N test. The excess amount of fertilizer applied to each plot was calculated from the difference of what was applied (162 kg N/ha) and the amount needed as predicted by the new spring soil test. The results are given in Table 4.5. There was a significant correlation ($r^2 = 0.92$, significant at ≤ 0.01 probability) between the estimated N loss from a particular plot and the excess fertilizer applied to that plot.

The data in Table 4.4 also shows that the soil N (0-0.6 m) was on average 20.0 kg N/ha higher in the NT compared to MB treatment (significant at 0.05 probability level).

Table 4.4 Total soil nitrate nitrogen (0-0.6 m depth) for the two tillage treatments at different sampling dates.

Sampling Date	SOIL NITRATE NITROGEN (0-0.6 m)										SITE AVERAGE			
	PAIR # 1 (1,6)		PAIR #2 (2,3)		PAIR #3 (5,4)		Kg - NO ₃ -N/Ha							
	NT	CT	NT	CT	NT	CT	NT	CT	NT	CT	NT	CT	NT	A
April 11/89	50.2	26.7	28.8	19.9	26.5	18.7	35.2	21.8	13.4					
May 02/89	93.8	77.5	73.2	49.5	47.1	39.6	71.4	55.5	15.9					
June 06/89	87.8	108.4	83.7	94.1	88.4	89.5	86.6	97.3	-10.7					
July 10/89	42.8	60.6	67.9	35.6	78.7	90.6	63.1	62.3	- 0.8					
Aug. 9/89	153.7	53.6	118.8	23.5	62.1	82.5	111.5	53.2	58.3					
Sept. 6/89	43.0	168.9	69.4	18.2	67.6	44.1	60.0	77.1	-17.1					
Sept. 21/89	297.0	108.0	109.5	47.1	77.8	53.8	161.4	69.6	91.8					
Oct. 12/89	139.1	116.0	98.8	32.1	52.5	97.5	96.8	81.9	14.9					
Nov. 3/89	364.1	231.1	236.8	91.3	59.8	75.0	220.2	132.5	87.7					
Nov. 21/89	100.4	79.6	75.1	67.6	46.4	35.7	74.0	61.0	13.0					
Apr. 4/90	49.4	30.6	50.0**	37.1	37.9	35.6	43.7	34.4	9.3					
May 14/90	77.0	64.2	85.3	62.8	66.3	72.5	76.2	66.5	9.7					
May 31/90	91.0	71.9	82.6	73.6	69.7	82.6	81.1	76.0	5.1					
July 4/90	43.7	83.9	96.3	63.1	75.8	78.0	71.9	75.0	- 3.1					
Nov. 15/90	61.5	35.5	48.9	35.6	45.6	28.3	52.0	33.1	18.9					
May 17/91	79.4	86.0	72.1	-	92.0	56.7	81.2	71.4	9.8					
					AVERAGE		86.6*	66.8*	19.8* ±					
									30.7					

* Significantly different at .05 probability
 ** Estimated

Table 4.5 Predicted excess fertilizer N and leaching losses of N based on the soil balance.

Nitrogen	Pair #1 (1,6)		Pair #2 (2,3)		Pair #3 (5,4)		Average
	NT	CT	NT	CT	NT	CT	
-----kg N/ha-----							
Recommended ¹ Fertilizer	41.0	73.0	81.0	127.0	132.0	146.0	115
Excess Fertilizer	121.0	90.0	81.0	35.0	30.0	16.0	47
Leaching ² Loss	175.0	103.0	80.0	22.4	21.2	29.9	52

¹From spring N soil test

²From soil balance

4.6 Detailed Transport Experiments

Appendix X has a summary of the TDR resistance Ω readings for the different tillage treatments and replications. Table 4.6 presents the parameters obtained when the observed TDR breakthrough data are fit to the Convective Dispersion Equation (CDE) and the Convective Lognormal Transfer Function (CLTF) model. Data for both 20 cm and 40 cm are provided, including the mean and standard deviation of the volumetric water content. Figures 4.12 through 4.15 illustrate the model estimation and the observed data. Note that these curves depict worked data which indicate relative solute mass remaining in the TDR probes' zone of measurement (not the ohms readings). At time = 0, the salt tracer has been applied to the soil and all of it exists within the measurement depth. As time increases, the salt-free water being applied at the surface pushes the tracer through the soil profile causing the salt to "leak" past the ends of the TDR probes and out of the measurement zone. Thus, the relative solute mass decreases. This continues until no more solute exists within the measurement zone.

Note that these breakthrough curves differ in shape from those depicted elsewhere in this report (eg. figure 4.10) because these curves are cumulative functions as opposed to the others which are density functions. A more traditional-looking breakthrough curve is obtained from the cumulative functions by taking the first derivative.

Except for the very ends of the curves, the models fit the data quite well. Difficulties in fitting these models at both ends of the observed data were also encountered by Elrick et al. (1991). However, the steepest portions of the curve which, when differentiated, form the peak of the breakthrough curve, are well fitted by each model.

At a steady-state flux of water $q=1.0$ cm/day, there was no significant difference (0-0.05 probability level) in the measured soil water contents for the two tillage systems. With similar soil water contents, the solute velocity (v) should be similar in each tillage system because there would be equal volumes of water to displace. This assumes that all of the pores filled with water are contributing to solute flux. However, the no-till system shows a faster solute transport velocity than the moldboard treatment (0.11 cm hr⁻¹ vs. 0.08 cm hr⁻¹) and a shorter mean solute travel time as compared to the mouldboard system (190.0 hrs vs. 243.9 hrs, Table 4.6). This implies that, although the soil water content is similar in the two tillage system, less of the water is contributing to solute transport in the NT system. More pore domains must be blocked from participating in the transport process in the NT system than in the MB system.

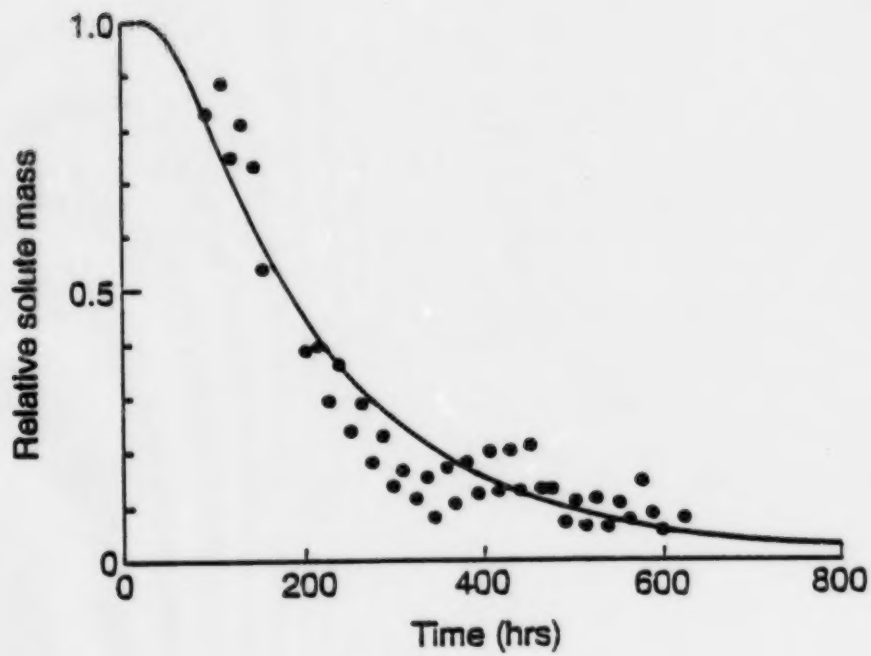


Figure 4.12: Field average solute mass breakthrough curves and fitted model predictions for the moldboard 0.20 m depth.

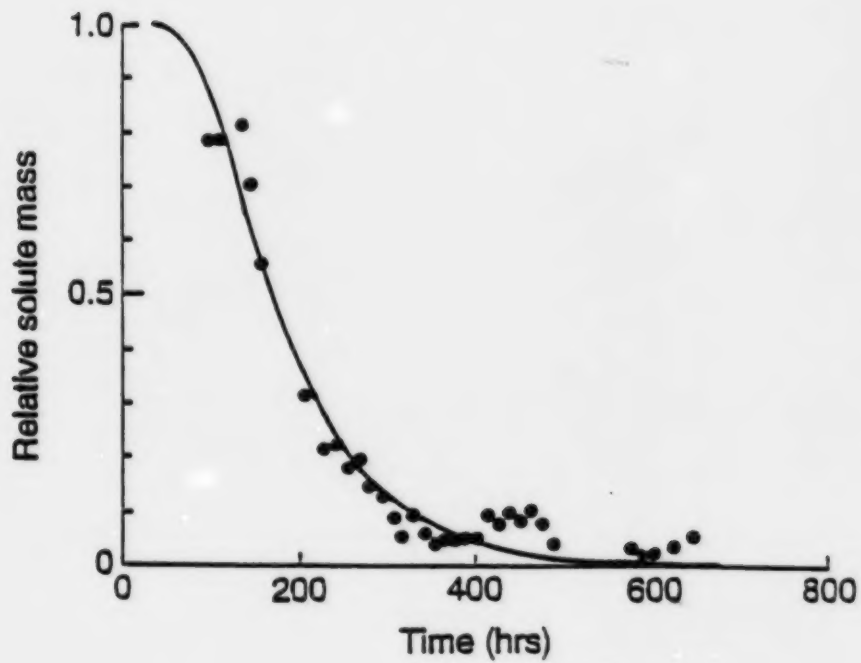


Figure 4.13: Field average solute mass breakthrough curves and fitted model predictions for the no-till 0.2 m depth.

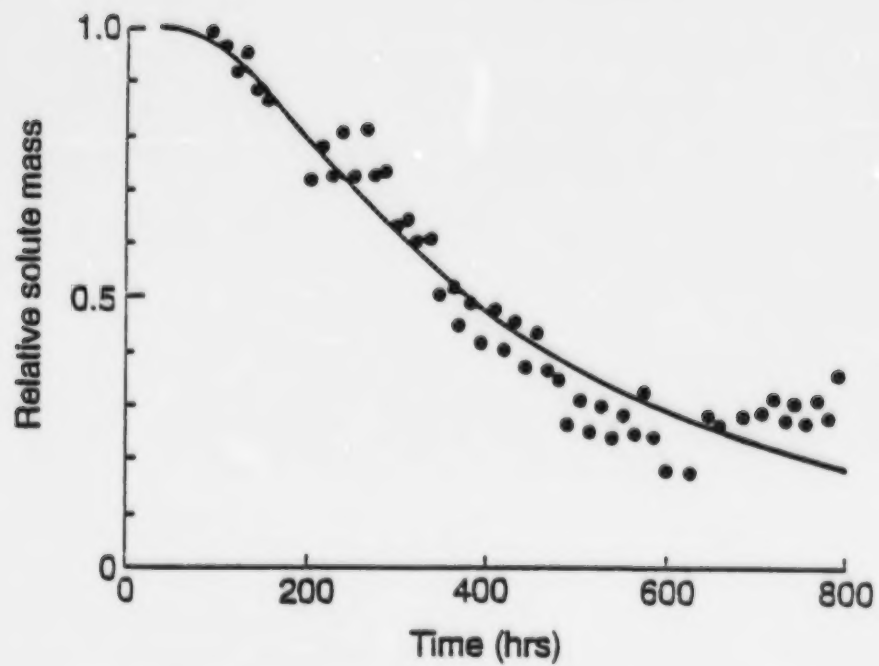


Figure 4.14: Field average solute mass breakthrough curves and fitted model predictions for the moldboard at 0.4 m depth.

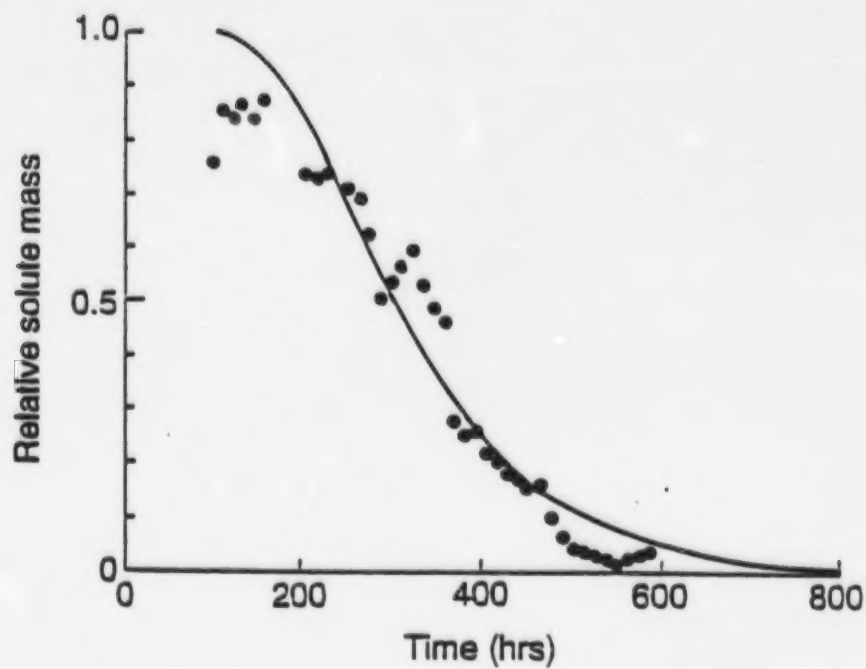


Figure 4.15: Field average solute mass breakthrough curves and fitted model predictions for the no-till 0.4 m depth.

In the 0-40 cm depth interval, the volumetric water content of the MB system was significantly lower by about 3 percent compared to the NT system. This gives an estimated soil water content of 27.5% (vol.) and 32.7% (vol.) in the 20-40 cm layer of the MB and NT system respectively. Solute velocity should increase with a decrease in water content because there is less water to be displaced. In the no-till system, water content remained about the same and a slight but not significant increase in velocity was observed. In the MB system the velocity also remained unchanged even though the soil water content was significantly lowered.

The population mean (μ_p) is a parameter comparable to the mean travel time estimate obtained with the CDE. The values are almost exactly the same for both μ_p and t_L . This is expected as both models will predict the same mean solute travel time. It is the spread or dispersion of the solute that is predicted differently (Kachanoski et al., 1990).

The dispersion coefficient D is an index of the spreading of the solute tracer around the mean or centre of the moving solute. It is an index of the range in solute velocities (or reciprocal travel times). The D value in the MB system was approximately 2x and 3x larger than the NT system at the 20 cm and 40 cm depths respectively. Similar difference between tillages were obtained for the solute travel time variance σ_p^2 estimates from the CLT model, which is the parameter describing solute spread in that model.

Conclusions about the effects of tillage on solute travel time characteristics using model parameters such as those given in Table 4.5 are only as valid as the ability of the model to describe the transport process. As indicated earlier, the models do not fit the early time data very well. The early time data is of interest because the occurrence of macropore flow will be observed in the early solute arrival times to a particular depth.

Table 4.7 provides information on the time taken for 5, 50, 90 and 95 percent of the solute to travel past the point of measurement. Note that at both the 20 and 40 cm depths, the first 5 percent of the solute reaching the measurement depths travelled faster in the MB compared to NT system (56 vs. 76 hours at the 20 cm depth and 112 vs. 156 hours at the 40 cm depth). This would suggest a larger number of macropores in the conventional system. The increase in the travel time in the MB is important with 5% of the applied tracer taking 1.5x longer to reach a depth in the NT compared to the MB system. However, the time for 50, 90 and 95% of the solute to reach a depth is far faster in the no-till system. This may be due to a smaller variance in pore size distribution in the NT system compared to MB system and more blocked pores. Table 4.7

Table 4.6: Solute transport parameters for the CDE and CLT model fits to the solute breakthrough data at 20 and 40 cm depths.

Depth (cm)	Management System	D_2 (cm ² /h)	CDE V (cm/h)	t (h)	μ	σ	CLT μ_p (h)	σ_p^2 (h ²)	Average Vol. Water Content %
0-20 cm	no-till	0.27	0.11	190.0	5.1	0.5	191.7	9800	32.8 (6.0)*
		0.6	0.08	243.9	5.2	0.8	247.9	48000	32.7 (4.7)
0-40 cm	no-till	0.44	0.12	333.3	5.7	0.4	333.1	22000	32.7 (3.9)
		1.2	0.08	526.3	6.0	0.8	432.5	260000	30.1 (3.2)
	moldboard								
	moldboard								

*Value in brackets are standard deviations.

Table 4.7 Time required for 5, 30, 50, 90 and 95% of solute to pass 20 and 40 cm depths.

Depth (cm)	Management System	Time for Solute to Pass Point of Measurement				
		5%	30%	50%	90%	95%
20	no-till	76	126	162	300	355
	moldboard	56	122	184	509	670
40	no-till	156	246	306	522	605
	moldboard	112	245	367	1018	1341

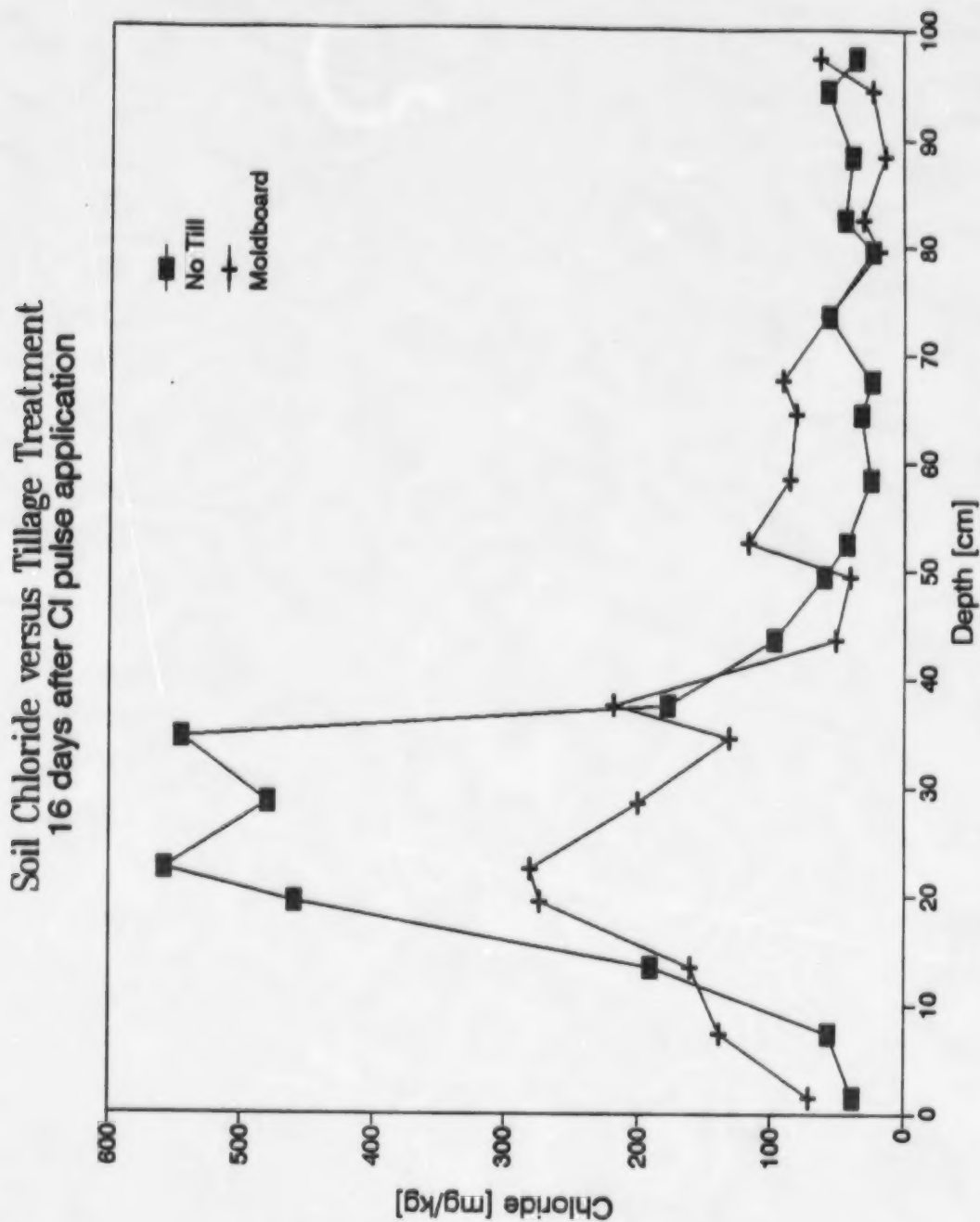


Figure 4.16: Average soil chloride distribution as a function of depth for No Till and Moldboard Treatments.

Soil Chloride in sites 4 and 5 35 days after Cl pulse application

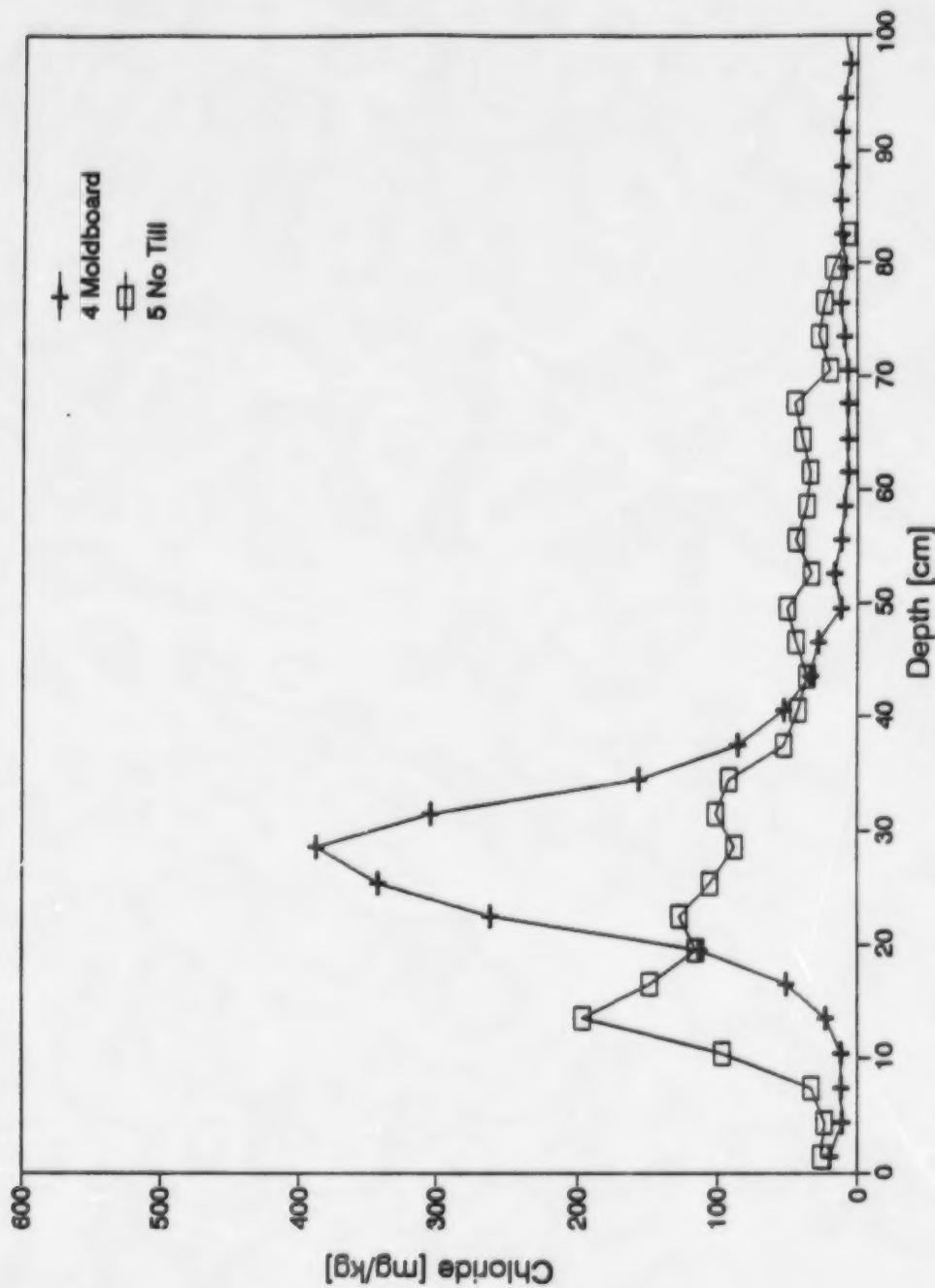


Figure 4.17: Average chloride concentration as a function of soil depth

on Dec. 4, 1989 for NT site # 5 and MB site # 4.

Drainage Experiment 1989/90 Chloride Conc. in the Tile Line

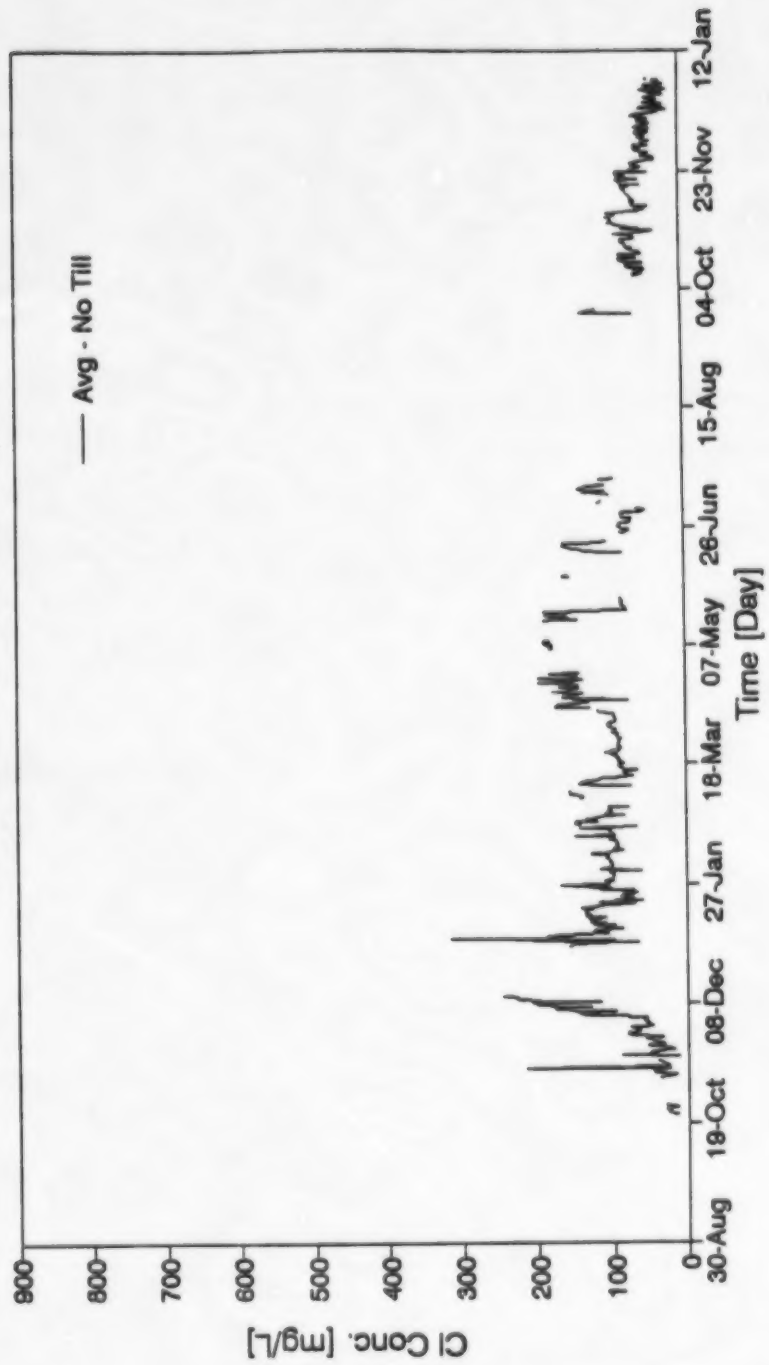


Figure 4.18: Average chloride concentration in the tile flow of the No Till treatment.

Drainage Experiment 1989/90 Chloride Conc. in Tile Line

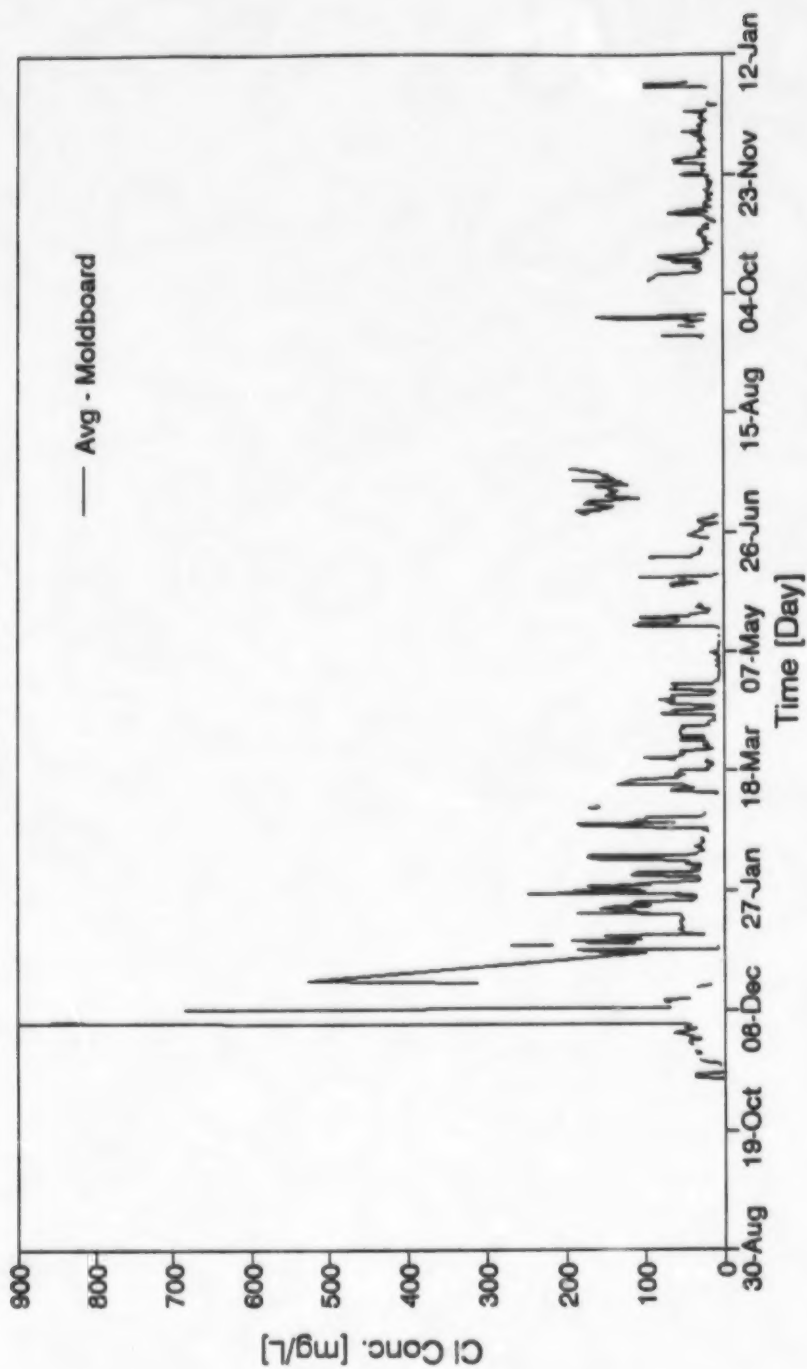


Figure 4.19: Average chloride concentration in the tile flow for the Moldboard treatment.

Drainage Experiment 1989/90
Chloride Conc. in Tile Line

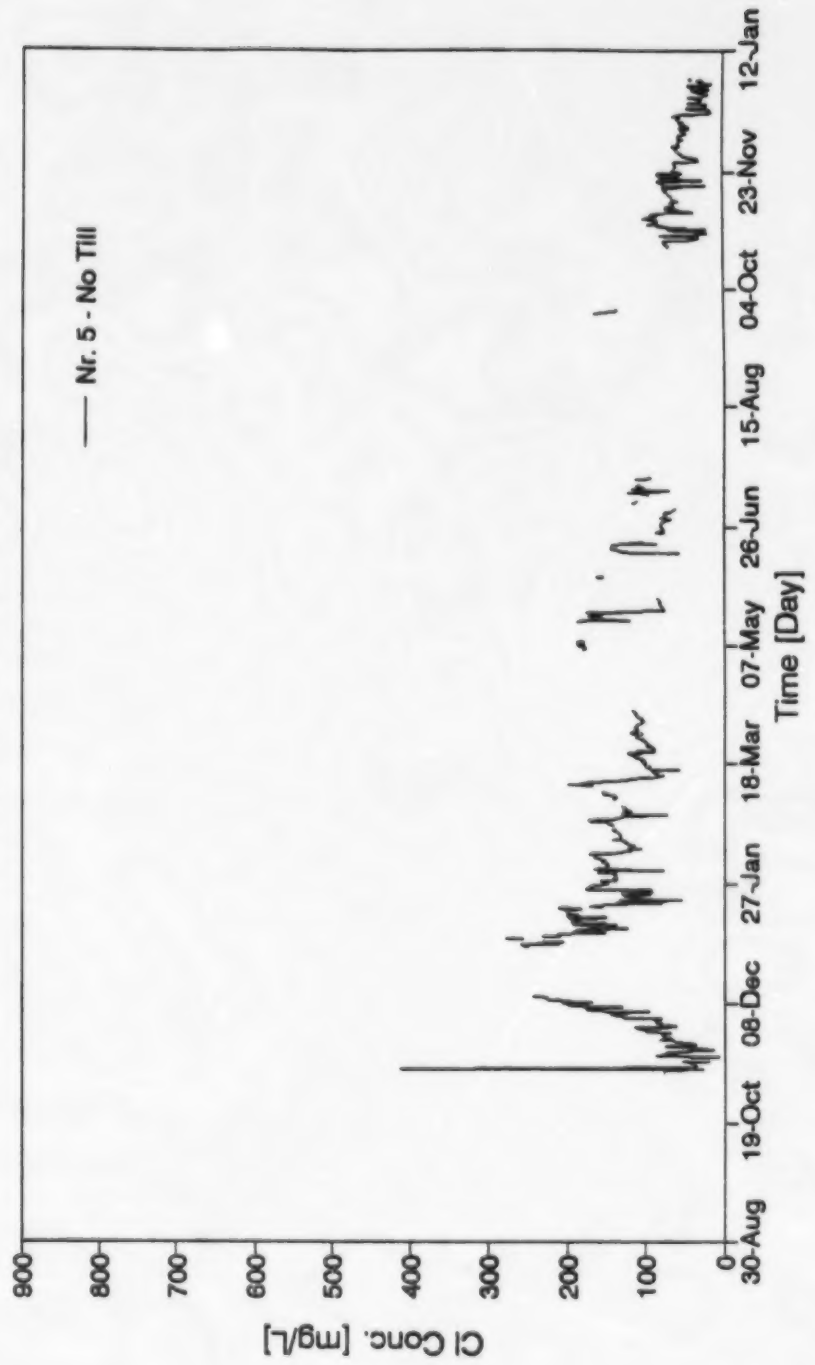


Figure 4.20: Chloride concentration in the tile flow of the No Till site # 5.

indicates that it also takes much longer for all of the solute to leave the MB system. Again, this is likely due to a wider range in pore size distribution in the MB system.

The solute transport characteristics are consistent with the soil sampling data from Nov. 22, 1989, obtained approximately 3 weeks after the field chloride pulse was applied. The average distribution of chloride mass as a function of soil depth indicates a portion of the MB chloride has moved faster through the soil than the bulk of the chloride (Figure 4.16) and faster than the chloride movement in the NT. The spread on the MB treatment chloride distribution is also larger. The data given in Figure 4.16 are the field average of 2 cores per replication of each tillage system. Individual cores show considerable variability. For example, two single cores taken on Dec. 04, 1989 from the MB#4 and NT#5 show the opposite results (Figure 4.17). Thus, it must be concluded that there is macropore flow in both tillage systems, but on a field average it is more predominant in the MB treatment. The increased average transport velocity in the NT is probably a result of more blocked pore domains and not an increase in macroporosity compared to the MB system.

The occurrence of macropore flow is also illustrated in the graphs of average chloride concentration in the tile water, as a function of time in figure 4.18 and Figure 4.19 for the NT and MB tillage respectively. The chloride was applied on day 304 (Oct. 31). As indicated in figures 4.18 and 4.19, some of the chloride reached the tile lines within 1 week after application. The very large increases in concentration are under conditions of low tile flow and thus represent less than 1% of the total chloride mass applied. However, the data does indicate that some of the applied chemical can move very quickly to the water table. The MB treatment has more sharp increases and decrease in the chloride concentrations especially in the period just after application. This again suggests more macropores in the MB treatment. Macropores are present in the NT treatment as indicated in the chloride concentrations for NT site #5 (Figure 4.20) and in the soil core data (Figure 4.17). However, the occurrence of macropores seems lower in the NT than in the MB treatment.

The results from the detailed transport experiments are consistent with the detailed measurements of hydraulic properties on the Lobb site (O'Neill et al. 1991, Kachanoski et al. 1989). In general, NT resulted in lower porosity, lower macroporosity, and a lower saturated hydraulic conductivity. The lower macroporosity in the NT is consistent with the faster movement of the first 5% of the solute chloride in the MB treatment. The faster average transport velocity in the NT has to be due to blocked pore regions that formed during the consolidation of the NT soil. Thus, there is less water to displace generally and therefore faster transport on average for the NT treatment. This should not be confused with macropore transport which is higher in the MB treatment and is the very fast transport for a small fraction of the solute.

4.7 Surface Water Quality and Quantity

4.7.1 Runoff Collection From Natural Events

As indicated in the Objectives, the goal was to measure soil and phosphorus losses from natural rainfall events on the large runoff plots. Unfortunately, the instrumentation for these measurements occurred in 1988, and no runoff events of any significance were recorded up to the spring of 1990. This was part of a general dry period experienced by most of Southwestern Ontario and the very high permeability of the soil at this site. Because of the expense of this kind of monitoring (dismantling and setting-up each time a field operation would occur), and the little data being generated, this part of the study was not pursued beyond May 1990. The experimental design and instrumentation for this part of the project were given for documentation of activity in the project.

4.7.2 Runoff Simulation Fall, 1988

Summaries of the total water runoff, soil loss, ortho-phosphate (runoff water), sediment, total P, and total P loss for the low intensity rainfall (0.67 mm/min for 15 min) on the moldboard and no-till treatments are given in Table 4.8 and Table 4.9 respectively. The same information for the high intensity rainfall simulation (2.8 mm/min for 10 min) is given in Tables 4.10 and 4.11. An average comparison between treatments is shown in Table 4.12. At the low intensity, total soil loss and total phosphorus loss were 54% and 30% higher respectively in the moldboard plough compared to no-till treatment. However, actual water runoff was 230 percent higher (over double) in the no-till compared to moldboard. Thus, considerably more water, but cleaner water, ran off the no-till plots. The dissolved ortho-phosphorus levels in the runoff water for both treatments was very low. The increased runoff in the no-till could pose problems with surface transport of chemicals if they are concentrated at the surface.

At the high intensity rainfall, total runoff was approximately 10% higher in the no-till compared to moldboard. The moldboard plow treatments on tillage pairs 2 and 3 had more runoff and considerably more soil loss. These pairs are upper slope positions, which have been severely eroded in the past. This can be seen by the chemical analysis of the surface soil (Table 4.13). These pairs have the lowest organic carbon and highest CaCO_3 (subsoil incorporation) of all pairs. Across all tillage pairs soil loss and phosphorus loss was 2.23 x and 2.15 x higher in the moldboard compared to no-till treatment.

Tables 4.8 through 4.11 reveal an interesting trend associated with tillage type and slope position. All of the lower slope position NT treatments produced more runoff than the upper position at both rainfall intensities. Conversely, for the MB treatments, the upper slope positions

Table 4.8. Summary of rainfall simulation data for moldboard treatment for low intensity rainfall (0.67 mm min^{-1}) for 15 minutes.

Tillage Pair	Replication number	Water runoff	Soil loss	Ortho phosph.	Sediment phosph.	Total P loss
		(cm)	(t ha ⁻¹)	(mg l ⁻¹)	(mg kg ⁻¹)	(kg ha ⁻¹)
Hill #2	1	0.49	0.28	< .10	745	0.209
Lower	2	0.10	0.13	< .10	540	0.070
	3	0.00	0.00	-	-	0.00
	\bar{x} =	0.20	0.23	<0.10	428	0.093 (.106)
Hill #2	1	0.28	0.38	< .10	490	0.182
Upper	2	0.18	0.12	< .10	540	0.065
	3	0.08	0.08	< .10	450	0.036
	\bar{x} =	0.18	0.18	<0.10	493	0.096 (.080)
Hill #1	1	0.25	0.32	< .10	450	0.144
Upper	2	0.20	0.21	< .10	445	0.093
	3	0.35	0.28	< .10	475	0.133
	\bar{x} =	0.27	0.27	<0.10	457	0.123 (.027)
Hill #1	1	< 0.05	0.07	< .10	380	0.0266
Lower	2	0.10	0.14	< .10	420	0.059
	3	0.05	0.14	< .10	400	0.056
	\bar{x} =	0.07	0.11	<0.10	400	0.047 (.179)

Table 4.9. Summary of rainfall simulation data for no-till treatment under low intensity rainfall (0.67 mm min^{-1}) for 15 minutes.

Tillage Pair	Replication number	Water runoff	Soil loss	Ortho phosph.	Sediment phosph.	Total P loss
		(cm)	(t ha ⁻¹)	(mg l ⁻¹)	(mg kg ⁻¹)	(kg ha ⁻¹)
Hill #2 Lower	1	0.34	0.11	<0.10	520	0.057
	2	0.43	0.08	<0.10	575	0.046
	3	0.35	0.16	0.18	460	0.074
	\bar{x} =	0.37	0.12	<0.10	518	0.059 (0.014)
Hill #2 Upper	1	0.45	0.11	<0.10	600	0.066
	2	0.07	0.05	<0.10	440	0.022
	3	0.23	0.06	<0.10	525	0.032
	\bar{x} =	0.25	0.07	<0.10	522	0.040 (0.023)
Hill #1 Upper	1	0.38	0.13	<0.10	480	0.062
	2	0.38	0.17	<0.10	420	0.071
	3	0.20	0.06	<0.10	500	0.030
	\bar{x} =	0.32	0.12	<0.10	467	0.055 (0.022)
Hill #1 Lower	1	0.56	0.18	<0.10	450	0.081
	2	0.58	0.15	<0.10	525	0.079
	3	1.07	0.32	<0.10	650	0.208
	\bar{x} =	0.74	0.21	<0.10	542	0.123 (0.074)

Table 4.10. Summary of runoff simulation data for moldboard treatment and high intensity rainfall (2.8 mm min^{-1}) for 10 min.

Tillage Pair	Replication number	Water runoff	Soil loss	Ortho phosph.	Sediment phosph.	Total P loss
		(cm)	(t ha ⁻¹)	(mg l ⁻¹)	(mg kg ⁻¹)	(kg ha ⁻¹)
Hill #2 Lower	1	0.32	0.38	<0.1	555	0.211
	2	1.11	0.97	0.62	510	0.565
	3	0.55	0.59	<0.1	545	0.322
	\bar{x} =	0.66	0.73	<0.21	537	0.366 (.181)
Hill #2 Upper	1	1.31	1.04	<0.1	520	0.541
	2	1.72	1.60	<0.1	575	0.920
	3	1.55	1.14	<0.1	540	0.616
	\bar{x} =	1.53	1.26	<0.1	545	0.692 (.201)
Hill #1 Upper	1	2.03	3.19	<0.1	450	1.436
	2	2.11	2.54	0.25	525	1.387
	3	2.70	4.37	<0.1	540	2.360
	\bar{x} =	2.28	3.37	0.08	505	1.728 (.548)
Hill #1 Lower	1	1.88	0.79	< .1	720	0.567
	2	1.96	0.92	0.33	770	0.773
	3	1.99	0.91	0.20	750	0.723
	\bar{x} =	1.94	0.87	0.18	747	0.688 (0.107)

Table 4.11. Summary of runoff simulation data for no-till treatment and high intensity rainfall (2.8 mm min⁻¹) for 10 minutes.

Tillage Pair	Replication number	Water runoff	Soil loss	Ortho phosph.	Sediment phosph.	Total P loss
		(cm)	(t ha ⁻¹)	(mg l ⁻¹)	(mg kg ⁻¹)	(kg ha ⁻¹)
Hill #2 Lower	1	1.80	0.51	<0.10	500	0.255
	2	0.65	0.25	<0.10	440	0.110
	3	1.98	0.61	<0.10	670	0.409
	\bar{x} =	1.48	0.46	<0.10	537	0.258 (0.150)
Hill #2 Upper	1	0.85	0.61	<0.10	550	0.336
	2	0.85	0.32	<0.10	470	0.150
	3	0.28	0.15	<0.10	470	0.07
	\bar{x} =	0.66	0.36	<0.10	497	0.185 (0.136)
Hill #1 Upper	1	2.25	0.79	0.50	410	0.436
	2	2.55	1.20	<.10	425	0.510
	3	1.88	0.62	<.10	410	0.25
	\bar{x} =	2.23	0.87	0.167	415	0.399 (0.134)
Hill #1 Lower	1	2.70	0.92	<0.10	760	0.699
	2	2.38	1.05	<0.10	560	0.588
	3	2.56	1.37	<0.10	760	1.04
	\bar{x} =	2.55	1.11	<0.10	693	0.776 (.236)

Table 4.12. Comparison of average water, soil and phosphorus loss in the two treatments.

Rainfall Intensity	Tillage Pair	Water runoff		Soil loss		Total P loss	
		(cm)		(t ha ⁻¹)		(kg ha ⁻¹)	
		No-till	Moldboard	No-till	Moldboard	No-till	Moldboard
Low	Hill #2 Lower	0.37	0.20	0.12	0.23	0.059	0.093
	Upper	0.25	0.18	0.07	0.18	0.049	0.096
	Hill #1 Upper	0.32	0.27	0.12	0.27	0.055	0.123
	Lower	0.74	0.07	0.21	0.11	0.123	0.047
	\bar{x} =	0.42	0.18	0.13	0.20	0.069	0.090
High	Hill #2 Lower	1.48	0.66	0.46	0.73	0.258	0.366
	Upper	0.66	1.53	0.36	1.26	0.185	0.692
	Hill #1 Upper	2.23	2.28	0.87	3.37	0.399	1.728
	Lower	2.55	1.94	1.11	0.87	0.776	0.688
	\bar{x} =	1.73	1.60	0.70	1.56	0.405	0.869

Table 4.13: Texture of runoff sites.

MOLDBOARD PLOUGH													
Site/tillage Replication		Particle Size Analysis											
Number	Texture	Gr	VCS	CS	MS	FS	VFS	Sand	Silt	Clay	pH	CaCl ₂	O.M.
-----% by wt-----													
Hill #2													
Lower													
1	SICL	0.5	0.1	0.5	3.5	7.2	6.3	17.6	53.7	28.7	7.2	1.4	3.3
2	SICL	2.6	0.1	0.6	3.3	7.0	5.4	16.4	54.9	28.7	7.2	1.3	3.1
3	SICL	0.4	0.3	0.7	3.8	7.2	5.0	17.1	53.4	29.5	7.2	2.8	3.3
Upper													
1	SICL	0.3	0.1	0.8	4.0	7.7	3.7	16.2	52.5	31.3	7.4	2.6	2.5
2	SICL	0.4	0.3	0.8	4.4	8.2	4.0	17.8	52.4	29.8	7.3	2.4	2.3
3	SICL	0.6	0.3	0.7	5.1	10.3	5.0	21.5	49.3	29.2	7.3	2.0	2.3
Hill #1													
Upper													
1	L	0.6	0.1	0.8	7.5	14.2	12.3	34.8	42.6	22.6	7.3	3.9	2.5
2	L	0.3	0.0	0.7	7.7	16.2	13.4	38.0	39.8	22.2	7.3	4.2	2.5
3	L	0.6	0.5	0.7	7.5	14.9	14.6	38.2	39.4	22.4	7.3	3.7	2.4
Lower													
1	feL	0.4	0.0	0.5	28.9	31.9	10.3	71.7	20.0	8.3	7.1	3.7	2.4
2	feL	0.6	0.2	0.5	31.3	32.2	9.3	73.5	18.2	8.3	7.1	2.3	2.5
3	feL	0.1	0.1	0.5	32.1	32.7	8.7	74.1	16.7	9.2	7.1	1.9	2.3

*Gr = gravel, VCS = very coarse sand, MS = medium sand, FS = fine sand, VFS = very fine sand
 O.M. = Organic matter

Table 4.13: Continued

Site/ Slope	Replication	Mo-Till												
		Particle Size Analysis*												
	Number	Texture	Gr	VCS	CS	MS	FS	VFS	Sand	Silt	Clay	pH	CaCO ₃	O.M.
Hill #2 Lower	1	SICL	0.6	0.7	0.7	3.3	6.1	3.3	14.1	53.7	32.2	7.4	2.0	3.2
	2	SICL	0.9	0.1	0.7	3.5	6.3	3.2	13.9	54.1	32.0	7.4	2.6	3.2
	3	SICL	0.7	0.3	0.6	3.7	7.1	3.6	15.4	53.2	31.4	7.4	3.0	3.1
Upper	1	SICL	0.1	0.1	0.5	3.7	8.0	3.9	15.3	52.4	31.3	7.3	1.5	3.1
	2	SICL	1.6	0.2	0.6	4.1	8.4	4.1	17.4	52.0	30.6	7.3	0.8	3.3
	3	SICL	0.4	0.6	0.6	4.0	9.5	4.4	19.3	53.5	27.2	7.3	1.0	3.2
Hill #1 Upper	1	L	0.5	0.3	0.8	5.6	10.1	7.6	24.5	49.1	26.4	7.3	2.7	2.3
	2	L	0.4	0.3	0.6	5.9	11.0	10.3	28.1	47.8	24.1	7.3	3.0	2.3
	3	L	0.6	0.5	0.7	5.3	9.8	14.8	31.1	44.3	24.6	7.3	2.7	2.3
Lower	1	faL	0.4	0.2	0.3	20.6	29.9	15.6	66.5	21.5	12.0	7.2	5.8	2.3
	2	faL	0.4	0.2	0.4	23.9	29.0	14.5	67.9	20.4	11.7	7.2	3.7	2.3
	3	faL	0.2	0.0	0.3	25.1	30.0	19.9	68.3	20.4	11.3	7.2	2.8	2.3

*Gr = gravel, VCS = very coarse sand, MS = medium sand, FS = fine sand, VFS = very fine sand

yielded more runoff than the lower slope positions; except for the low intensity simulations on Hill #2, which produces about the same amount of runoff.

In summary, soil loss and phosphorus loss was higher on the moldboard compared to the No-till treatment. Increased runoff water from the no-till compared to moldboard was not expected. In addition as indicated in Table 4.12, decreasing the rainfall intensity resulted in a much more significant decrease in runoff volume in the moldboard than in the no-till treatment.

A detailed discussion of the hydrologic soil properties measured at the site for each replication is given in O'Neill et al 1990. The average field saturated hydraulic conductivity K_s values showed the same trend as the measured runoff values. No-till resulted in a significantly lower K_s than moldboard and the K_s values were significantly lower grassed and 8 yr no-till compared to 1 yr no-till (Table 14, O'Neill et al. 1990). This is consistent with the increased runoff water on the no-till (Table 4.12).

The average matric flux potential ϕ_m and subsequently predicted time to surface ponding T_p , also indicate more runoff should have been expected in the no-till treatment (O'Neill et al. 1990). The initial soil water content was also significantly higher in the no-till ($\theta_i = 0.47$) compared to moldboard treatment ($\theta_i = 0.37$). Thus, less available pore space was available to accept the incoming rain water. In addition, the ability of the matrix to absorb water by capillary forces (characterized by ϕ_m) was significantly lower in the no-till ($\phi_m = 4.0 \text{ m}^2\text{s}^{-1} \times 10^{-4}$) compared to moldboard ($\phi_m = 0.2 \text{ m}^2\text{s}^{-1} \times 10^{-4}$). All of these factors resulted in a predicted time to ponding that was very much larger in the moldboard treatment.

The measured time to 5% ponding (since 100% ponding never occurred) is given in Table 4.15 for the low intensity rainfall simulation. Again, the measured T_p was significantly higher in the moldboard compared to no-till treatment. The high intensity sites ponded very quickly (5% area) and the data are not very reliable. The time to run-off generation was also 4 x longer in the no-till compared to moldboard (Table 4.15).

The decrease in K_s , and ϕ_m , and subsequent increase in runoff in the no-till treatment is attributed to a decrease in total porosity and macroporosity in the no-till compared to moldboard treatment (O'Neill et al. 1990). This is attributed to a consolidation in the soil in the no-till treatment which is indicated also by a significant increase in bulk density in the no-till. Apparently the formation of stable macropores in the no-till has not occurred enough to offset the overall decrease in

Table 4.14: Summary of average field saturated hydraulic conductivity measured with the pressure infiltrometer.

<u>Field Saturated Hydraulic Conductivity</u>					
K_s (cm hr ⁻¹) ^a					
Site/Slope	Texture	Moldboard	1 yr No-till	8 yr No-till	Grassed
Hill #1					
Lower	FSL	24.1 ^a	9.0 ^a	6.5 ^b	
Upper	L	49.1 ^a	9.1 ^b	10.2 ^b	1.2 ^c
Hill #2					
Lower	SiCL	17.4 ^a	56.9 ^b	0.80 ^c	
Upper	SiCL	52.9 ^a	15.8 ^b	1.5 ^c	
Hill #3					
Lower	CL	<u>30.6^a</u>	<u>23.4^a</u>	<u>6.2^b</u>	—
Overall average	K_s	34.9 ^a	22.8 ^{ab}	5.0 ^b	1.2

Average of 4-5 replications

Value in the same row with different letters are significantly different at the 5% probability level.

Table 4.15: Runoff hydrograph characteristics for low intensity rainfall simulation (0.67 mm min⁻¹).

Tillage	Replication	Time to Ponding(s)		Time to Runoff(s)	
		No-till	Moldboard	No-till	Moldboard
Hill #2 Lower	1	29	45	75	210
	2	25	50	105	110
	3	24	40	90	1200
	\bar{x} =	26	45	93	507
Hill #2 Upper	1	20	55	210	90
	2	20	45	370	180
	3	21	100	245	650
	\bar{x} =	20	67	275	307
Hill #1 Upper	1	20	90	85	135
	2	31	70	90	150
	3	25	90	52	270
	\bar{x} =	25	81	76	185
Hill #1 Lower	1	37	270	70	810
	2	60	210	185	720
	3	45	210	60	600
	\bar{x} =	47	230	105	710
Overall mean * =		30(12) ^a	106(84) ^a	137(93) ^b	427(230) ^b

*Values with the same letter are significantly different at the 1% probability level.

porosity caused by a lack of tillage disturbance.

4.7.3 Runoff Simulation April 1990

The simulations described for Oct., 1988 were repeated in April 1989. The moldboard treatment was ploughed in November, 1988, so the effects of fall ploughing and over-winter consolidation could be assessed. The one-year no-till treatment was ploughed so it was not sampled again. Sampling in April was carried out on two adjacent plot locations, a 10 m x 1.6 m permanent runoff plot and 1 m x 1 m rainfall simulation plot. In June, 1989 only the permanent plots were monitored. The information collected allows for a temporal as well as spatial comparison of runoff, erosion, phosphorus loss and surface hydraulic properties in the two tillage systems. Once again the runoff data were collected in a co-operative project with the Ontario Ministry of Environment project.

A summary of the data collected for each individual replication of the Guelph Pressure Infiltrometer GPI, along with the calculated hydraulic parameters, were given for both the permanent runoff and 1 m x 1 m plots in Appendices 2a and 2b respective, of O'Neill et al. (1990). Calculated porosity indices were given in Appendices 2c and 2d of O'Neill et al. (1990). Included are measurements of bulk density, soil water content versus matric flux potential ψ_m , and calculated pore size distributions for all undisturbed cores sampled in April, 1989.

A summary of the average K_s measurements for April, 1990 for both large and small runoff plots was given in Table 4.16 (O'Neill et al 1990). Both the GPI measurements and data from the standard core method suggest that less, not more water will infiltrate into the no-till treatment. This is identical to the conclusions from the fall data. The data also indicate that the spatial variability of K_s significantly higher in the MB than in the NT treatment. The standard deviation of the MB is 2x that of the Nt treatment.

The overall average time to ponding for each slope position over both large and small plots is given for each treatment in Table 4.17. The data predicts that, on average, time to ponding would be much lower in the 9 year no-till treatment than in the moldboard. The T_p values are quite variable between sites which negated any statistical difference, but all sites at both intensities had lower T_p for the NT compared to MB. This data can now be compared to the observed data from the rainfall simulation experiments on the same soil landscape positions. During the April sampling period rainfall simulation trials were completed only on the 1m x 1m plots. Table 4.18 illustrates the observed runoff at the high (2.8 mm·min⁻¹) rainfall intensity for the 1m x 1m plots. The data are consistent with measurements from the fall of 1988. The no-till resulted

Table 4.16: Overall average of K_{t_1} readings for moldboard plough versus no-till by slope position at D. Lobb site ($\text{m}\cdot\text{s}^{-1} \times 10^{-5}$) - April, 1989.

Texture		Moldboard		No Till		
		\bar{X}	S	\bar{X}	S	
Hill 1	Lower Upper	fSL	1.34	0.89	0.69	0.65
		L	2.35	3.12	1.46	2.89
Hill 2	Lower Upper	SiCL	1.24	2.05	0.105	0.09
		SiCL	5.50	4.11	1.28	1.32
Overall Average		MB	2.83 ^{a1}	3.32 ^A	0.91 ^b	1.61 ^B

¹Values in same row with different letters are significantly different at 0.01 probability level

Table 4.17: Comparison of overall average predicted time to ponding for April sampling period (D. Lobb).

Site/Slope	Rain Intensity	Calculated Time to Ponding(s)	
		MB	NT
Hill 1	Lower		
	Low	715	727
	High	42	43
Upper	Low	1242	653
	High	73	38
Hill 2	Lower		
	Low	602	25
	High	35	1
Upper	Low	3700	1460
	High	219	86
Overall Average	Low	1567 ^{a,1} (1455)	726 ^a (587)
	High	92 ^a (86)	42 ^a (35)

(standard deviation)

¹Values in the same row with different letters are significantly different at 0.05 probability level.

Table 4.18: Runoff characteristics of Lobb simulation (2.8 mm min^{-1} for 12 min.) in April, 1989.

Site/Slope/Tillage	Time to Ponding (sec)	Water runoff (cm)	Steady-state runoff rate (cm/hr)	Steady-state infiltration (cm/hr)	Soil loss (t/ha)	Total Phosphorus Loss (kg/ha)
Hill #1 Lower	MB 49	1.18	9.3	7.5	3.9	5.9
	NT 30	1.53	11.4	5.4	1.72	1.25
Upper	MB 25	0.71	8.1	8.7	4.2	1.30
	NT 22	1.70	12.4	4.4	0.5	0.36
Hill #2 Lower	MB 10	0.33	3.1	13.7	1.39	0.45
	NT 13	0.84	7.4	9.4	0.85	0.57
Upper	MB 12	0.19	2.0	14.8	0.65	0.26
	NT 11	1.21	10.4	6.4	1.70	1.28
Avg	MB 24	0.60	5.6	11.2	2.5	1.98
	NT 19	1.32	10.4	6.4	1.2	0.87

Table 4.19: Runoff characteristics of Lobb simulation (0.67 mm min^{-1} for 25 min) in April, 1989 for no-till.

Site/Slope/Tillage	Time to Ponding (sec)	Water runoff (cm)	Steady-state runoff rate (cm/hr)	Steady-state infiltration (cm/hr)	Soil loss (t/ha)	Total Phosphorus Loss (kg/ha)
Hill #1	Lower	0.07	0.63	3.4	1.2	0.88
	Upper	0.12	0.80	3.2	0.1	<0.05
Hill #2	Lower	0.10	0.40	3.6	0.10	0.06
	Upper	0.10	0.60	3.4	<0.1	0.06
Ave	245	0.10	0.60	3.4	0.1	0.26

Table 4.20: Comparison of measured time to runoff T_R and predicted time to ponding T_P .

Rainfall Intensity	MB		NT	
	T_P	T_R	T_P	T_R
-----sec-----				
Low	1567	>1500	716	726
High	92	183	42	98

Table 4.21: Summary of average treatment effects on porosity indices from all cores sampled at D. Lobbs - April 1989 sampling period.

Site/Slope	Bulk Density ($\text{g}\cdot\text{cm}^{-3}$)		Total Porosity ($\text{m}^3\cdot\text{m}^{-3}$)		Macroporosity ($\text{m}^3\cdot\text{m}^{-3}$)		Relative Macroporosity (%)	
	MB	NT	MB	NT	MB	NT	MB	NT
Hill 1 Lower	1.39	1.45	0.478	0.460	0.065	0.046	13.4	10.0
Upper	1.48	1.64	0.452	0.425	0.016	0.051	16.3	12.0
Hill 2 Lower	1.37	1.54	0.521	0.443	0.12	0.048	22.0	10.9
Upper	1.36	1.66	0.524	0.468	.118	0.047	22.1	8.4
Average	1.4 ^{a1}	1.57 ^b	0.494 ^a	0.449 ^b	0.093 ^a	0.048 ^b	18.4 ^a	10.3 ^b
S.D.	0.10	0.11	0.039	0.03	0.04	0.013	4.32	1.52

¹ Values for each soil parameter with different letters are significantly different at the 0.01 probability level

in higher runoff rates (lower infiltration) than the moldboard system. However, as in the fall data, the total soil loss and phosphorus loss from the moldboard treatment were more than 2 x higher than the no-till.

The low intensity rainfall simulation data for the Lobb site during the April sampling period is summarized for only the no-till (Table 4.19) because the low intensity storm failed to generate any runoff, or soil loss from the moldboard site. Thus under very low intensity rains, no-till may have higher soil and P loss rates because runoff is generated in the no-till and not in the moldboard. For high intensity storms the moldboard again generates less water runoff than the no-till, but the water which runs off is laden with sediment and phosphorus. This illustrates the need to interpret single event data very carefully. Depending on the event characteristics you would reach opposite conclusions.

The runoff data in Table 4.18 and Table 4.19 are consistent with the predicted values for time to ponding T_p and measured surface hydraulic properties. Comparisons of the measured time to runoff T_R and predicted time to ponding are given in Table 4.20 and indicate a good relationship. Even the zero runoff from the moldboard treatment under low intensity is predicted by the T_p estimate in the rainfall simulation for the low intensity lasted 1500 seconds (25 min) and estimated $T_p = 1567$ seconds. Note, that the estimated T_p is related to the time of runoff generation T_R , and not measured time to ponding. Measured time to ponding is usually, time to 5% area ponding while the estimated time to ponding is an areal effective average.

The changes in surface hydraulic properties and subsequent effects on the runoff and soil loss are probably a result of increased bulk density and lower overall soil porosity in the no-till compared to moldboard as shown in the 1988 fall measurements. The measured porosity indices in both the permanent and 1m x 1m plots have been summarized by O'Neill et al. 1990. A summary of this data are given in Table 4.21. The average bulk density value in the no-till is 12% higher than the moldboard and the total porosity of the no-till is $0.45 \text{ m}^3 \cdot \text{m}^{-3}$ compared to $0.494 \text{ m}^3 \cdot \text{m}^{-3}$ in the MB treatment. The decrease in total porosity for the no-till is identical to the measured decrease in the macroporosity of $0.045 \text{ m}^3 \cdot \text{m}^{-3}$, in the NT compared to the MB treatment. The decreased macroporosity would therefore account for the decreased infiltration, K_{sat} , K_a and increased water runoff observed in the no-till plots.

In order to compare the quality of the runoff water in more detail, the resolution of measuring dissolved ortho-phosphorus in the lab was increased and the runoff water analysed. The water was also analysed for

Table 4.22: Ortho-phosphorus and Nitrate-N concentrations in runoff water from the Lobb April, 1989 (High intensity) 2.8 mm·min⁻¹.

Site/Tillage	code (REP#)	Ortho-phosphorus (mg/l)		Nitrate-N (mg/l)		
		MB	NT	MB	NT	
Hill #2 Lower	7	0.09	0.05	0.30	0.3	
	8	0.10	0.12	0.39	0.28	
	9	<u>0.02</u>	<u>1.08</u>	<u>0.24</u>	<u>0.29</u>	
	X	0.07	0.08	0.31	0.29	
	Upper	10	0.02	0.08	0.29	0.40
		11	0.05	0.10	0.40	0.36
		12	<u>0.07</u>	<u>0.07</u>	<u>0.26</u>	<u>0.28</u>
		X	0.05	0.08	0.32	0.35
		Hill #1 Upper	13	0.03	0.45	0.29
	14		0.03	0.08	0.27	0.25
	15		<u>0.07</u>	<u>0.11</u>	<u>0.30</u>	<u>0.33</u>
	X		0.04	0.21	0.29	0.33
Lower	16		0.28	0.08	0.23	0.37
	17	0.13	0.10	0.32	0.58	
	18	<u>0.08</u>	<u>0.07</u>	<u>0.25</u>	<u>0.67</u>	
	X	0.16	0.08	0.27	0.54	
	Overall average		0.08	0.15	0.30	0.38

nitrate nitrogen. A summary of this data is given in Table 4.22. The data indicate, as in the Fall of 1988 that ortho-phosphorus in runoff was negligible, as is nitrate. The ortho-phosphorus values represent approximately 0.01 kg P/ha per cm of water runoff. There were no significant differences due to tillage. The overall average in the no-till is higher because one of the samples (rep. code #13 was very high). The remaining 11 reps had an average ortho phosphorus concentration of 0.08. For 7 of the 12 paired simulations; the NT ortho-phosphorus concentrations were higher than the MB. The average value of 0.08 mg/l is very similar to the values obtained by Spires and Miller (1978) for non manured fields in the PLUARG study where they examined runoff from 5 different agricultural watersheds. Their average for non-manured fields was also 0.08 mg P/l.

The nitrate-N values in the runoff water are also very low (<1.0 mg NO₃-N/l) and represent a minimal environmental concern from the field. This again is not surprising since most of the nitrogen fertilizer is applied by knifing in the fertilizer at time of sidedress, and manure is not applied on this site. In addition, the high infiltration rate of this soil would quickly move any soluble NO₃-N to depths below the surface of the soil.

4.7.4 Runoff Simulation June 1989

The Lobb site was again sampled in June of 1989 after the crop had emerged to see the effects of time, secondary tillage and planting on the surface hydraulic properties. A third sampling location, Hill No.3 was also sampled because of its different texture (i.e. clay loam). During this sampling period, only the permanent runoff plots were sampled and used for rainfall simulation because the 1m x 1m sites had been disturbed by field crews working in the area. All hydraulic readings were taken near the middle of the corn row to reduce disturbance to the emerging corn crop. Undisturbed cores were not taken at this time so as to minimize site disturbance for future rainfall simulation runs. The runoff simulation was carried out on the large permanent runoff plots using a large rainfall simulator (1.6m x 10m plots).

The measured data from the rainfall simulation experiments seen in Table 4.23 are consistent with the measured hydraulic properties for this site. Infiltration rates in the no-till were again on average higher, but not significantly different than those in the moldboard plots. The smaller difference may be related to increased scale of these plots. The total soil loss and phosphorus loss are much larger due to the increased severity of the rainstorm and the fact the simulation lasted for approximately 30 minutes compared to 10 normally. In addition, size of

Table 4.23: Runoff characteristics from D. Lobb rainfall simulation in June 1989 for large plots. (High intensity - $3.3 \text{ mm min}^{-1} = 20 \text{ cm h}^{-1}$).

		Runoff Rate (cm/h)	Infiltration Rate (cm/h)	Soil Loss (t/ha)	Time to Runoff (s)	Total Phosphorus Loss (Kg P/ha)
Hill#1	Lower	NT	11.5	6.6	120	2.38
		MB	11.5	6.6	60	6.61
	Upper	NT	8.5	9.6	36	3.73
		MB	17.3	0.8	20	10.99
Hill#2	Upper	NT	13.7	4.4	90	4.39
		MB	12.9	5.2	94	9.58
	Lower	NT	8.1	10.0	60	1.69
		MB	9.0	9.1	50	2.51
Hill#3	Lower	NT	18.0	0.1	80	4.77
		MB	17.9	0.2	40	6.98
	Upper	NT	18.1	<0.11	80	2.21
		MB	17.9	0.2	67	4.84
Average	NT	12.0 ^a (4.8)	5.1 ^a (4.4)	8.8 ^a (4.6)	78 ^a (28)	3.20 ^a
	MB	14.4 ^a (3.8)	3.7 ^a (3.8)	17.7 ^b (7.2)	55 ^a (25)	6.92 ^b

Values in each column with different letters are significantly different at (1) 0.05 or (2) *0.025 probability level

Table 4.24: Summary of hydraulic properties at D. Lobb's site for all measurement dates.

Hydraulic Property	Tillage	Oct. 1988	April 1989*	June 1989
K_{fs} ($ms^{-1} \times 10^{-5}$)	MB	9.14	2.84	4.50
	NT	1.26	0.91	1.72
K_{sat} ($ms^{-1} \times 10^{-5}$)	MB	9.89	60.55	N/A
	NT	0.94	18.80	N/A
ϕ_m ($m^2 s \times 10^{-6}$)	MB	4.04	2.68	5.43
	NT	0.22	1.14	1.79
α^* (m^{-1})	MB	24.5	10.6	8.3
	NT	42.7	7.8	9.6
T_p (s)	MB	210	92	187
	NT	4	42	123
ρ_b	MB	1.40	1.40	N/A
	NT	1.54	1.57	N/A
θ_{sat}	MB	0.486	0.494	N/A
	NT	0.449	0.449	N/A
θ_{macro}	MB	0.097	0.093	N/A
	NT	0.063	0.048	N/A

Table 4.25: Summary of steady infiltration rates for Lobbs on all dates (high intensity 3.3 mm min⁻¹).

		Steady Infiltration Rates (cm/hr)					
		Oct. 1988		April 1989		June 1989	
Site/Slope		MB	NT	MB	NT	MB	NT
Hill #1	Lower	5.4	2.9	7.5	5.4	6.6	6.6
	Upper	4.7	4.7	8.7	4.4	0.8	9.6
Hill #2	Lower	9.1	15.2	13.7	9.4	5.2	4.4
	Upper	<u>14.7</u>	<u>9.1</u>	<u>14.8</u>	<u>6.4</u>	<u>9.1</u>	<u>10.0</u>
Average		8.5	8.0	11.2	6.4	5.4	7.7

Table 4.26: Summary of soil loss at Lobbs on all dates (high intensity).
Soil Loss (t/ha)

		Oct. 1988		April 1989		June 1989	
Site/Slope		MB	NT	MB	NT	MB	NT
Hill #1	Lower	0.87	1.11	3.9	1.7	16.0	7.0
	Upper	3.37	0.87	4.2	0.5	28.0	9.0
Hill #2	Lower	0.73	0.46	1.4	0.9	23.0	16.0
	Upper	<u>1.26</u>	<u>0.36</u>	<u>0.7</u>	<u>1.7</u>	<u>7.0</u>	<u>3.0</u>
Average		1.56	0.70	1.98	0.9	18.5	8.8

Table 4.27: Summary of total phosphorus loss at Lobbs on all dates (high intensity 3.3 mm min⁻¹).

		Total Phosphorus Loss (kg P/ha)					
		Oct. 1988		April 1989		June 1989	
Site/Slope		MB	NT	MB	NT	MB	NT
Hill #1	Lower	0.69	0.78	5.90	1.25	6.61	2.38
	Upper	1.73	0.40	1.30	0.36	10.99	3.73
Hill #2	Lower	0.37	0.26	0.45	0.57	9.58	4.39
	Upper	<u>0.69</u>	<u>0.19</u>	<u>0.26</u>	<u>1.28</u>	<u>2.51</u>	<u>1.69</u>
Average		0.87	0.41	1.98	0.87	7.4	3.05

the plot was significantly increased (ie the size of the permanent runoff plots) to 16 m². The data indicate phosphorus loss was 2x higher in the MB compared to NT treatment.

Summaries of the average hydraulic properties for each slope position and sampling date are given in Table 4.24. The average rainfall simulation results are given in Tables 4.25 to 4.27. The data clearly show the consistent nature of the measurement over the three sampling dates. The long term no-till treatment is characterized by: higher bulk density, lower total porosity, lower macroporosity, shorter time to ponding, lower matric flux potential, lower field saturated hydraulic conductivity, lower saturated hydraulic conductivity, higher runoff (rainfall simulation), lower infiltration rate (rainfall simulation), lower soil loss (rainfall simulation) and lower total phosphorus loss (rainfall simulation) compared to the long term moldboard plough treatment. These effects were consistent across all sampling times except for runoff measurements in June and were not dependent on the time of sampling. In addition losses of ortho-phosphorus and nitrate-nitrogen in surface runoff were negligible with no significant differences in the tillage treatments.

Measurements of runoff, soil loss, and associated nutrients in the permanent runoff plots from natural rain storms were negligible with no events recorded. In fact the plots recorded no measurable rainfall events even into the late spring of 1990. A runoff event probably occurred in Jan., 1990 during a rapid snow melt, but the equipment was not functional for measuring snow melt events.

Little differences in dissolved ortho-Phosphorus in the runoff water of the NT and MB were observed (and quite low values) for the Oct./88 and April/89 simulations at the Lobb site. However, these sites were on the front of the field and had coarse textured surface soils and high infiltration rates. Thus, according to processes governing the movement of dissolved chemicals into runoff water, the convective downward flux from the surface may have been so high in these soils that the dissolved ortho-phosphorus was quickly moved away (deeper into the soil) from the soil surface.

The effect of surface texture on ortho-phosphorus runoff, and the temporal dynamics of ortho-phosphorus release to runoff water was also examined at the Lobb site as part of the cooperative research with the Ministry of Environment. Ortho-phosphorus in runoff water samples were

measured every minute from the large scale simulation plots at the largest (14.4 m^2) spatial scale. Sites #1 to #4 were on lighter textured LS soils at the front of the field, while sites #5 and #6 were on clay-loam soils at the back of the field. The average ortho-phosphorus in the runoff water as a function of time is given in Figure 4.21 and Figure 4.22 for the sandy-loam and clay-loam textured sites respectively.

The sandy-loam sites show some differences in the temporal dynamics of the ortho-phosphorus between NT and MB, but the average value was the same in both treatments. The general response is an initially high value with a subsequent exponential decline of ortho-phosphorus concentration in the run-off water as time increases. The MB sites show a light delay in the peak concentration runoff. The exponential decline observed in the data is identical to the theoretical curves and suggests the concentration of ortho-phosphorus is dependent on the interplay between convective and dispersive processes. The data also suggest that if a fixed time interval is set for runoff simulation, the concentration of ortho-phosphorus in the NT can be higher, lower or equal to that of the MB. This indicates the need to study the temporal dependence of the processes.

The ortho-phosphorus concentrations as a function of time for the clay-loam sites showed significantly higher values in the no-till compared to MB system. The value of ortho-phosphorus in the NT clay-loam soil runoff is also quite high averaging 0.21 (mg/l) compared to 0.07 (mg/l) in the MB site. It is also much higher than all other previous values (average= 0.08) from the lighter soils of the same field. The data indicate a definite interaction in tillage/soil texture with heavier textured soils under no-till showing much higher levels of ortho-phosphorus in runoff water.

The clay-loam NT soils also showed a significant increase in ortho-phosphorus concentration with time in the runoff as opposed to a decrease. The temporal pattern may be related to desorption kinetics of ortho-P from the clay adsorbing sites. More work is needed on the temporal dynamics and controlling processes related to ortho-phosphorus release to run-off.

The diffusion of ortho-phosphorus into runoff water would also be related to the magnitude of the concentration gradient between the ortho-phosphorus in the soil solution and in the runoff water. For non-manured runoff sites at Guelph, Spires and Miller (1978) found that ortho-phosphorus concentrations in runoff water were related to the bicarbonate

extractable P in the runoff sediment. It seems reasonable that the bicarbonate extractable P in the sediment is related to the bicarbonate extractable P in the source soil (which is the current phosphorus soil test for P in Ontario).

The bicarbonate extractable P in the top 0-5 cm of soil on the sandy-loam and clay-loam soils (both tillages) are given in Table 4.28. As indicated, the NT has a greater amount than the MB, but the difference is much more prevalent in the clay-loam soil. Thus the NT seems to have accumulated bicarbonate extractable P at the surface preferentially in the clay-loam compared to sandy loam soil. This accumulation along with low infiltration and subsequent convective flux of surface P is probably the reason for the increased ortho-phosphorus in the runoff of the NT clay-loam soil. No similar increase in bicarbonate soil P was measured in the MB clay-loam soil, and the ortho-phosphorus in the runoff was similar to both the MB and NT in the sandy-loam soils.

Many studies Baker and Laffeu (1983) have documented a build up of soil test P in the surface of no-till soils. This is disturbing because it suggests a significant risk of increased reactive P in surface runoff from the NT soils. This may only be a problem in heavier textured soils because the initial infiltration (up to the time of ponding) and subsequent high infiltration in lighter textured soils may cause a high convective flux of ortho-phosphorus away from the soil surface (deeper into the soil). Thus, only on heavy textured NT soils would a significant greater concentration gradient of dissolved P be present between the runoff water and the surface soil solution. These sites would show increased ortho-phosphorus concentrations in runoff water. More work needs to be done to confirm this hypothesis and to quantify the governing processes.

Table 4.28. Amount of bicarbonate extractable phosphorus in the different tillage and soil textures.

Bicarbonate extractable P ($\mu\text{g/g}$) (0-5 cm surface soil)		
Texture	NT	MB
LS	42	38
LS	<u>40</u>	<u>28</u>
X =	41	33
CL	54	28
CL	<u>56</u>	<u>32</u>
X =	60	30

5.0 SUMMARY AND CONCLUSIONS

5.1 Drainage Water

Total precipitation over approximately a year (Oct. 1, 1989 to Oct. 1, 1990) at the site was 121.0 cm. Tile drainage was estimated at 19.0 cm, with no significant differences between tillage systems. Movement of water below the tile line depth was estimated at 49.0 cm. By mass balance this gives an estimated total evapo-transpiration of 53.0 cm. The long-term average potential evapo-transpiration at the site is 61.0 cm.

No-till had a significantly higher average concentration and flux weighted concentration of $\text{NO}_3\text{-N}$ in the tile water for the spring and early-fall periods compared to moldboard plough. The opposite was true in late fall, early winter. No significant differences in average yearly $\text{NO}_3\text{-N}$ concentrations were found between the tillage systems. The average yearly flux weighted concentration was 10.1 and 11.1 mg $\text{NO}_3\text{-N/l}$ in the NT and MB treatments respectively. This was similar to the average groundwater concentration below (1.0 m to 5.0 m depth) the sites.

Average yearly $\text{NO}_3\text{-N}$ loss was estimated at 81.0 and 54.0 kg $\text{NO}_3\text{-N/ha}$ for the NT and MB treatment respectively. This was separated as 21.0 and 16.0 kg $\text{NO}_3\text{-N/ha}$ measured N loss in the tile line in the NT and MB treatments respectively, and 60.0 and 38.0 kg $\text{NO}_3\text{-N/ha}$ of N transport below the tile line in the NT and MB treatments respectively. The N transport below the tile line was estimated from the measured flux averaged $\text{NO}_3\text{-N}$ concentrations and the estimated 50 cm of water flux below the tile line. The water flux below the tile line was estimated by mass balance and the movement of a chloride tracer in the groundwater.

The estimated yearly $\text{NO}_3\text{-N}$ leaching losses of 81.0 and 54.01 kg N/ha compared very well with the measured soil N losses of 92.0 and 52.0 kg N/ha over the fall 1989 to spring 1990 period. Both the soil balance and leaching measurements compare favourably with an estimate of 77.0 and 47.0 kg N/ha excess fertilizer applied for the NT and MB treatments respectively. These numbers were obtained from the difference between the fertilizer applied (162.0 kg N/ha) and the recommended fertilizer needed for each treatment. The recommended fertilizer was based on the new N soil test for Ontario (Kachanoski and Beauchamp, 1991). The NT treatment had a significantly higher average soil test than the MB treatment, resulting in a lower fertilizer N requirement.

Individual plots had a wide variation in the N test. The predicted fertilizer excess in each plot was significantly correlated ($r^2 = 0.92$, prob. < 0.01) to the N leaching loss of each plot as estimated using the soil N balance. This suggests that differences in the inherent N fertility between plots are responsible for differences in N leaching and have caused the change in N fertility.

Detailed measurements of solute transport parameters and travel times using tracer experiments indicated the MB treatment had a greater occurrence of macropores and "fast" solute transport of a small portion of

the tracer applied. However, the bulk average transport velocity was faster in the no-till which was attributed to blocked pore domains. This resulted in less water transport volume for the infiltrating water to displace, and thus faster average transport. The decrease in macropore flow in the NT compared to MB is consistent with previous studies on the site showing lower occurrence of macropores. Both treatments had rapid transport of some of the tracer to the tile line. A new field method for estimating the solute travel time parameters using Time Domain Reflectometry was developed.

In conclusion, the NT system does not appear to increase the risk of groundwater contamination per se. The increased N leaching in the NT compared to MB was due to the constant fertilizer amount applied to both systems, when the NT sites needed significantly less fertilizer. If the plots had been fertilized individually according to the N test then extra leaching of N in the NT system should not be expected. The reasons for the increased N tests on the no-till sites is not known. The differences in tests may be related to plot positioning rather than tillage system. The results are consistent with a previous study by Miller (1979) which indicated that N loss was related to the amount of fertilizer N applied above the recommended rate. The study suggests the new N soil test may be an important management tool to minimize N leaching losses to the groundwater. However, further work needs to be carried out, and is in progress under the Partners In Nitrogen Project.

The effect of tillage on the transport of other chemicals is not straight forward. The moldboard system had greater macropore transport, thus the occurrence "fast" transport of some chemicals is higher in this system. However, the no-till had a higher average solute transport because of blocked pore domains (not increased macroporosity).

As a final note, the occurrence of more macropore transport in the moldboard system was not expected. However, it is consistent with detailed observations of the hydraulic properties at this site in other studies. A major research question is "why do no-till systems in Ontario have less macropore transport than tilled systems". One hypothesis is that the horizontal ice lenses which form during the freezing of our soils disrupt the continuity of macropores.

Phosphorus transport in water from the tile lines was negligible and is not an environmental concern at this site in either tillage systems.

The study also indicated that monitoring tile lines may be a good method of obtaining flux averaged concentrations of chemicals leaving the root zone. However, it may not give a reliable estimate of total nutrient loss (kg/ha) over the year because of significant transport of chemicals past the tile lines, to deep groundwater zones. Multi-level groundwater samplers coupled with tracers should allow this component of leaching to be quantified.

5.2 Surface Water Quality

Surface runoff from rainfall events from either the NT or MB

treatments at this site is negligible. The very high surface infiltration rates of the sandy loam soil are the main reasons for the low runoff rates. Detailed runoff plots failed to measure any runoff from natural rainfall events over a 20 month period. The lack of surface runoff is consistent with the drainage component of the study, where the movement of the chloride pulse could be estimated from precipitation and evapotranspiration values (ie no runoff).

For rainfall events which would exceed the infiltration capacity of the site, the rainfall simulation studies showed considerably more runoff water in the no-till treatment. This was consistent with detailed studies on surface hydraulic properties at the site, which showed significantly lower field saturated hydraulic conductivity, porosity, and macro-porosity in the no-till compared to moldboard treatment.

Although runoff was less in the moldboard compared to NT, the water from the MB was laden with sediment and phosphorus. The rainfall simulations indicated phosphorus losses were 2 - 4x higher in the MB compared to NT treatment. These results were consistent through fall, spring, and summer measurements.

Dissolved ortho-phosphorus and nitrogen concentrations in the runoff water were negligible in both the NT and MB for the sandy-loam part of the field. Significantly higher concentrations of ortho-phosphorus were measured in the NT treatment in the clay-loam textured part of the field. This was related to the higher bi-carbonate extractable P in the surface 0-5 cm of the NT compared to MB treatment.

In summary, surface water quality problems (P and N) at this study site are minimal with no significant differences due to tillage. The data suggest that dissolved phosphorus and other chemicals may be a problem in the increased surface runoff in the NT, but this is likely to only be the case for heavier textured soils.

In conjunction with the drainage results, the study suggests NT is a good method of protecting water quality (surface and sub-surface) at this site.

6.0 Recommendations

The following recommendations are made as a result of the findings of this study.

In studies involving drainage tiles, special care should be taken in the design or modification of the existing drainage system to avoid back-pressure problems, ie. overdimensioning the headers, ensuring a steeper than usual slope of the discharge tubes and that the outlet will be above the river water level with heavy rainstorms.

More work needs to be done to confirm and quantify the governing processes on the hypothesis of a greater buildup of soil test P in the surface of heavy textured than loamy to sandy soils under no-till.

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